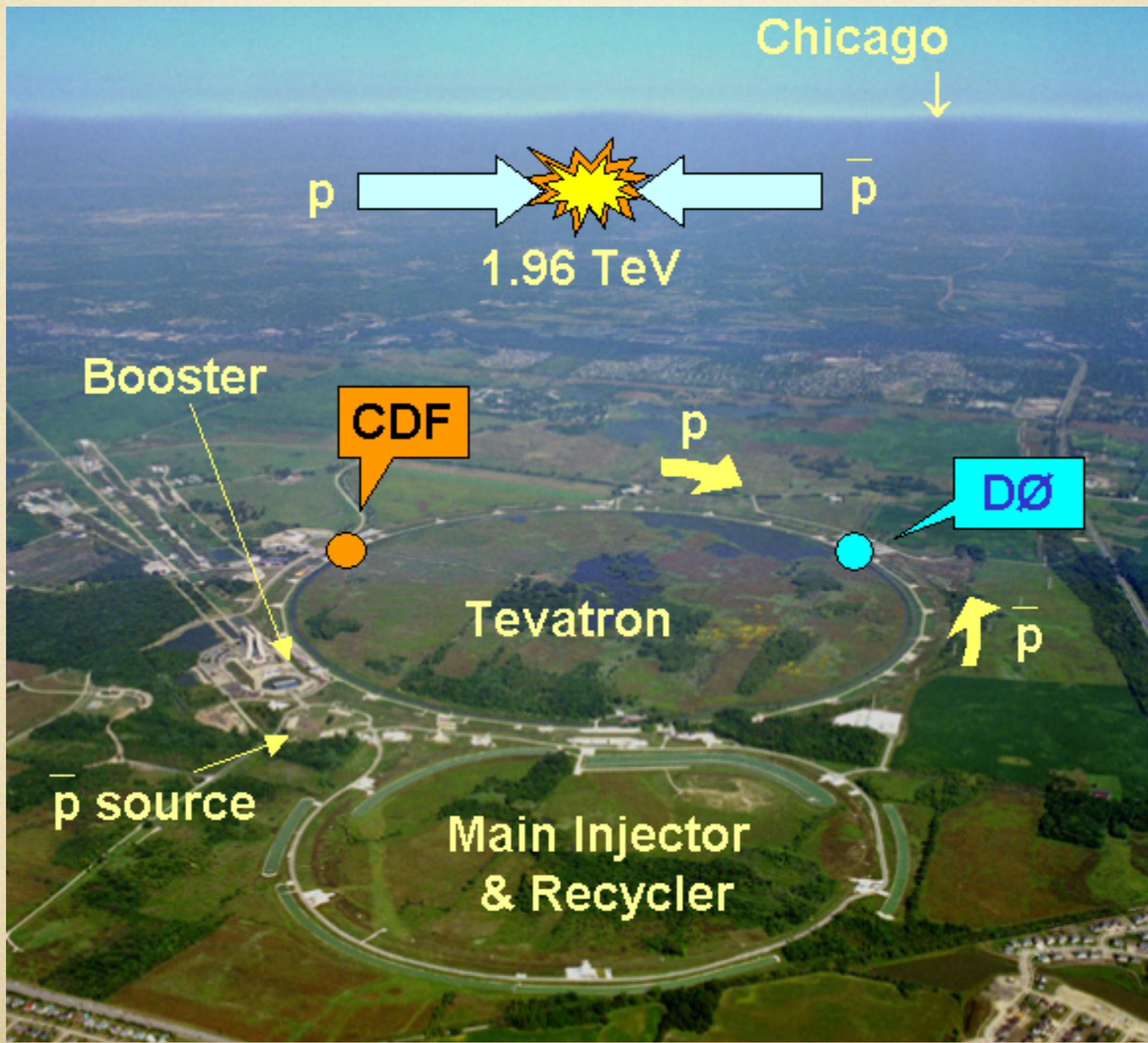


# Higgs Hunting at the Tevatron

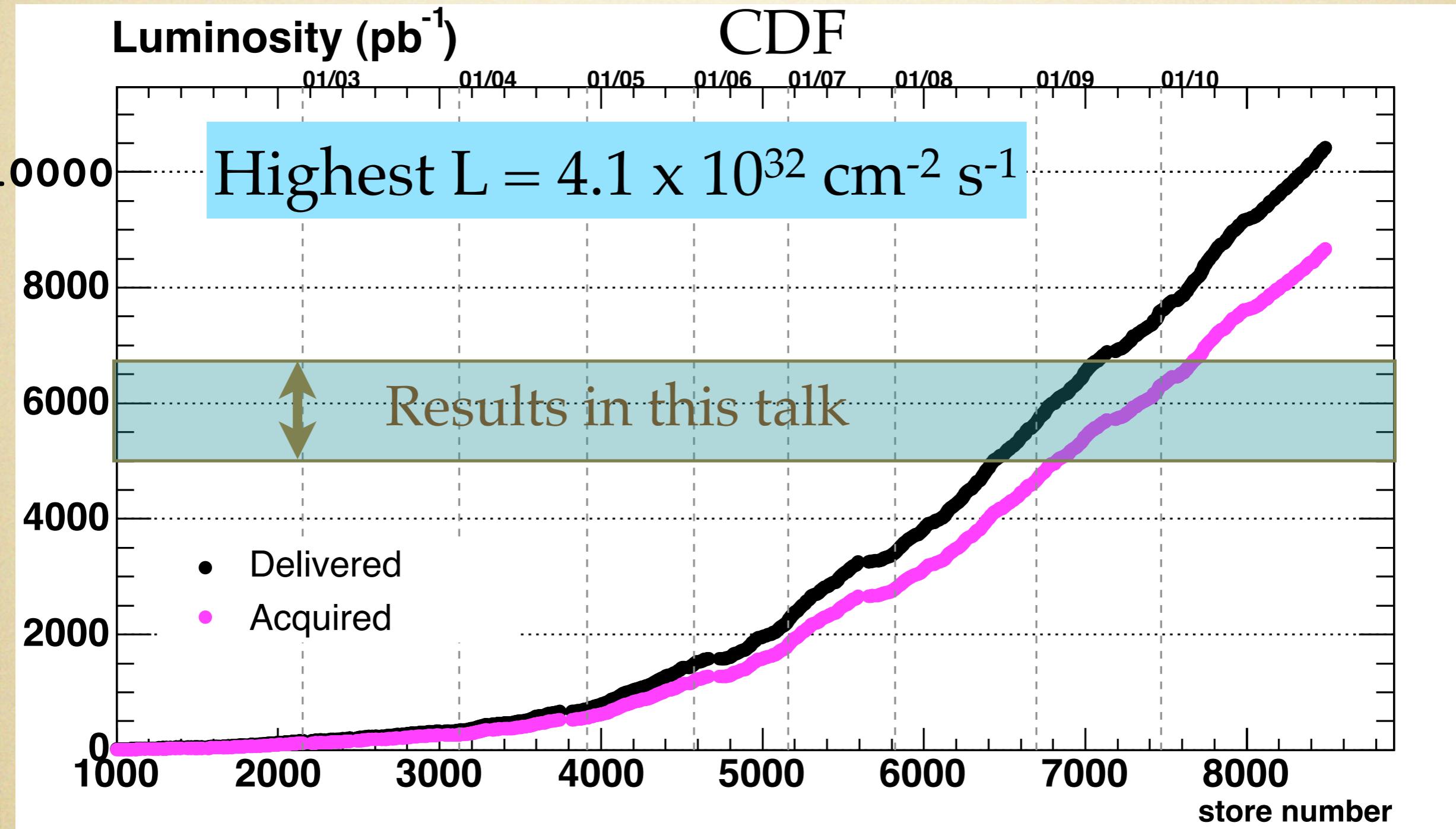
Brian L. Winer  
The Ohio State University  
for  
The CDF and DO Collaborations

Lake Louise Winter Institute, Feb 2011

# Tevatron



# Tevatron Performance



# DZero Experiment

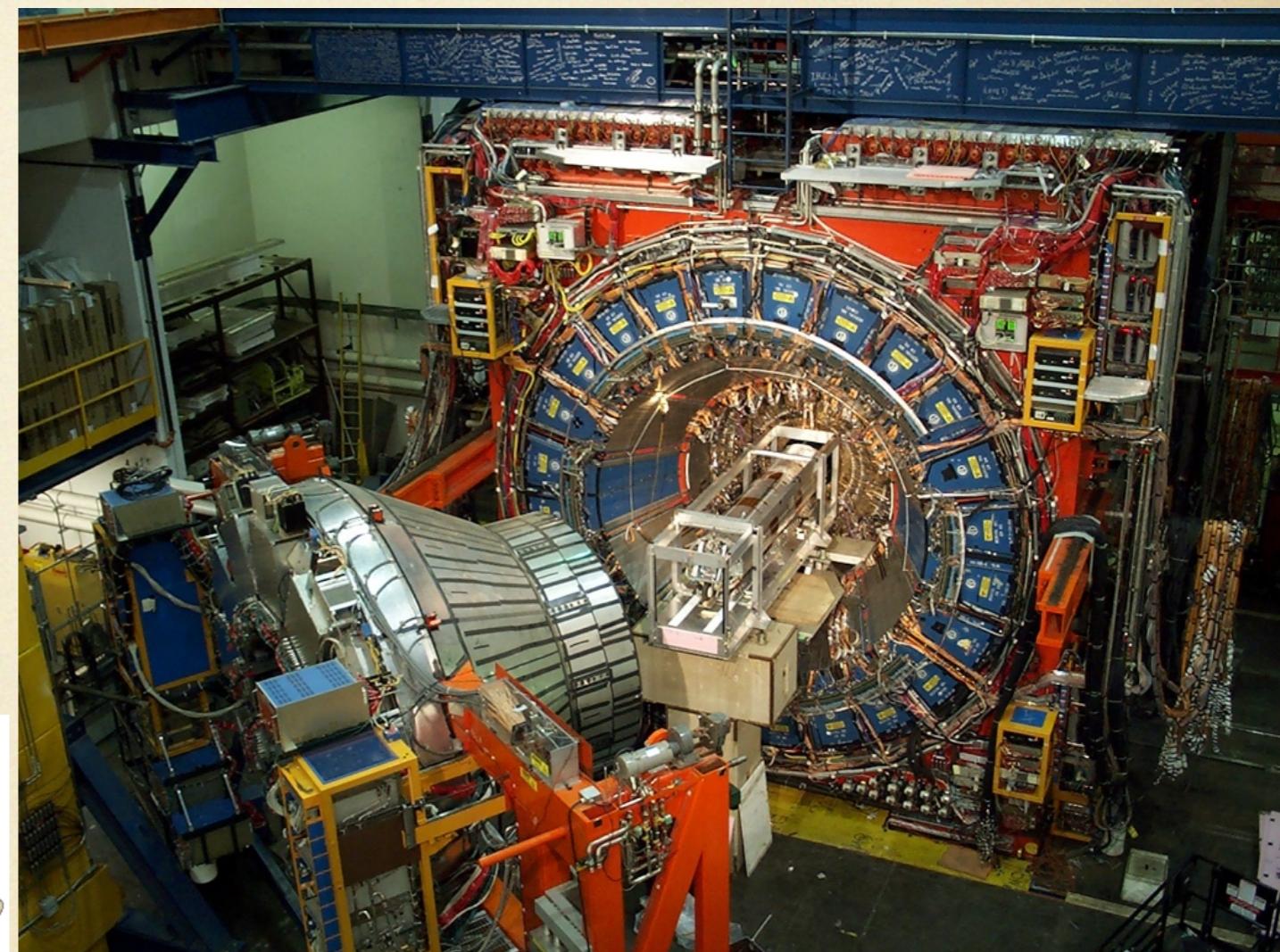
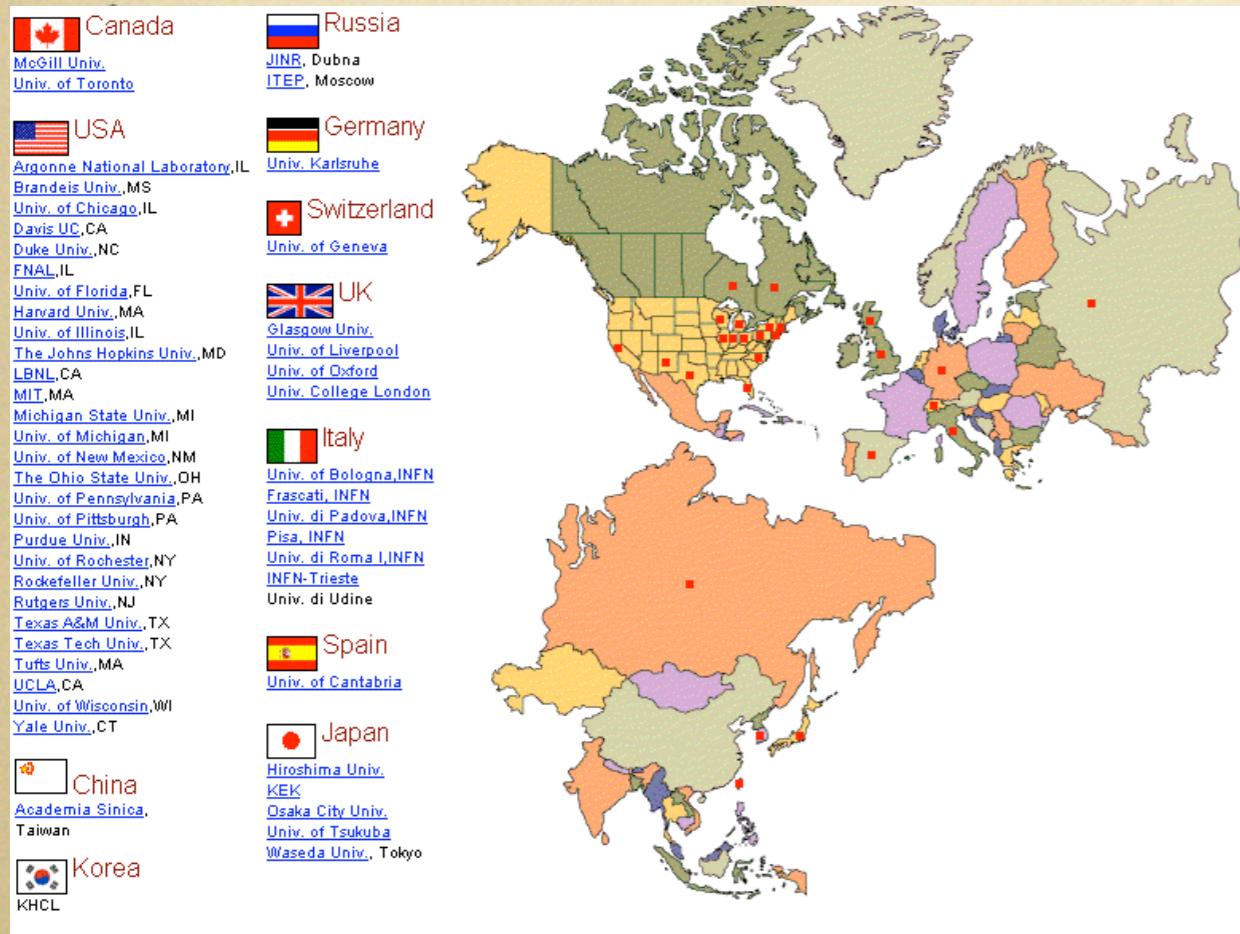
Multi-purpose detector.  
Multi-national collaboration



- First data: 1992
- Uranium-LAr Calorimeter
  - \* Excellent Energy Resolution
- Fiber/Si Tracking Systems
  - \* Lepton&b-quark identification

# CDF Experiment

- First data: 1985
  - \* Upgraded many times
- Scin. Tile Calorimeter
- Large Drift chamber & Si Tracking Systems
  - \* Excellent tracking resolution



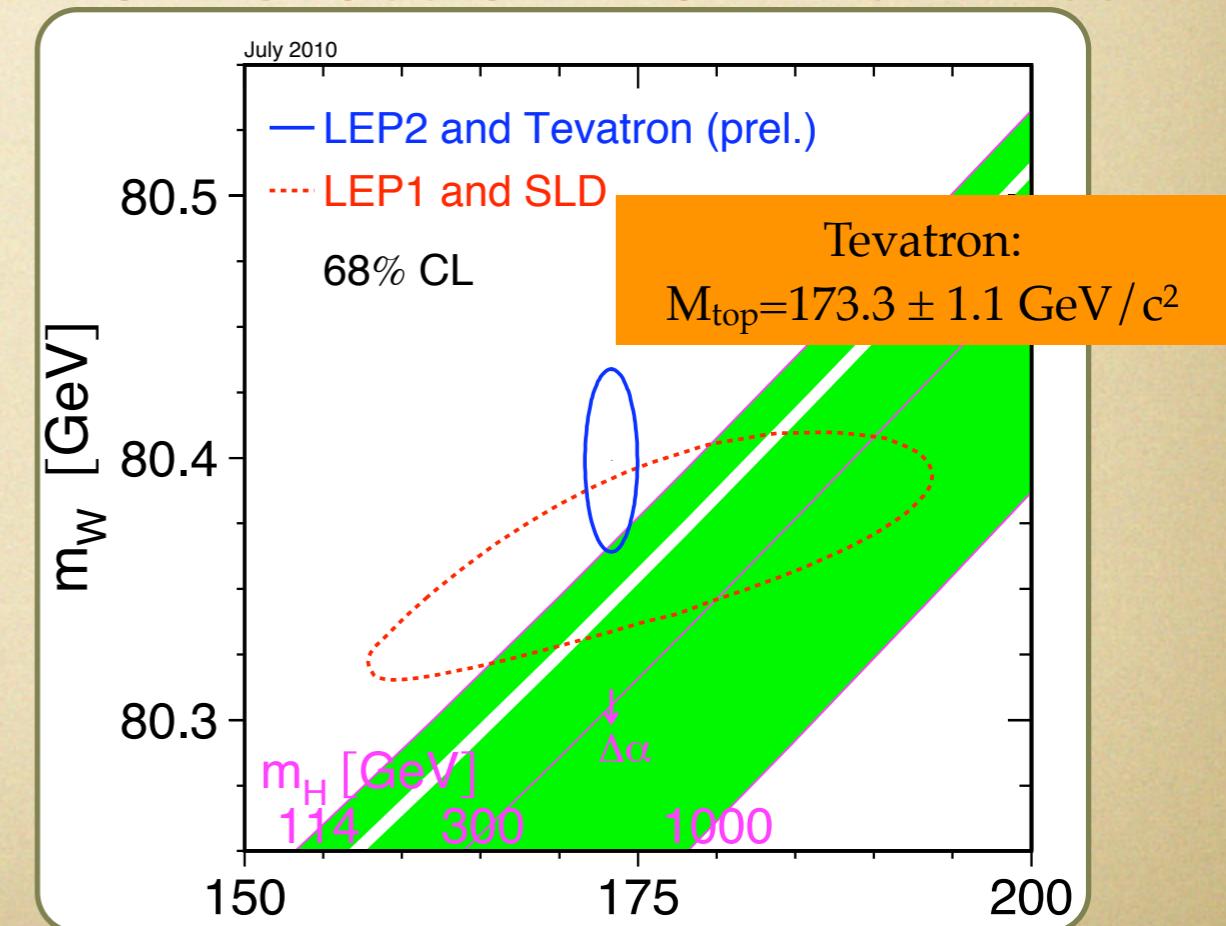
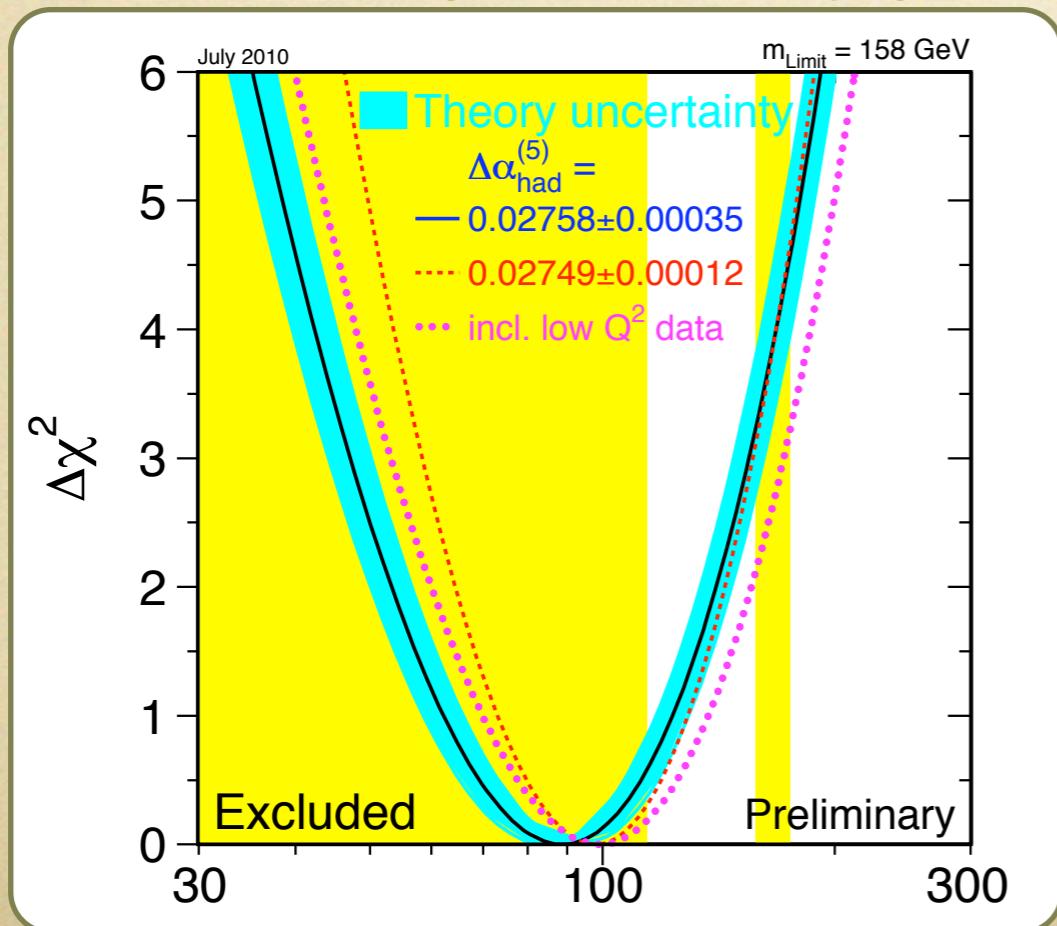
Multi-purpose detector.  
Multi-national collaboration

# Standard Model Higgs

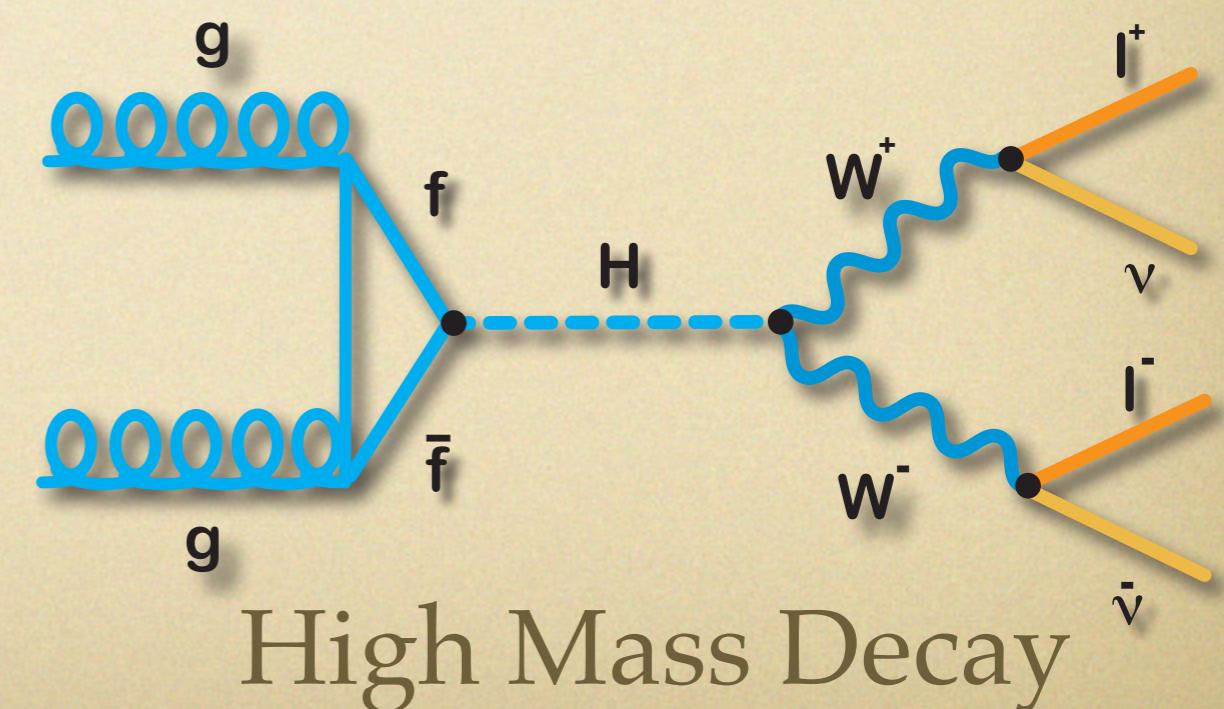
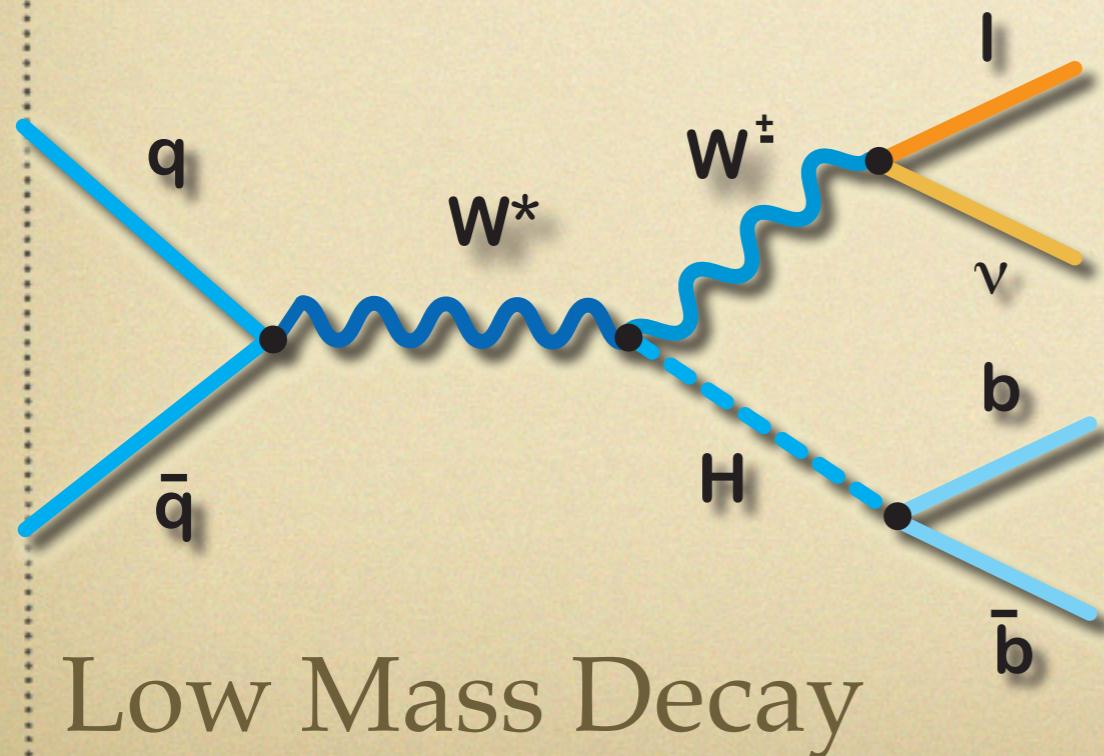
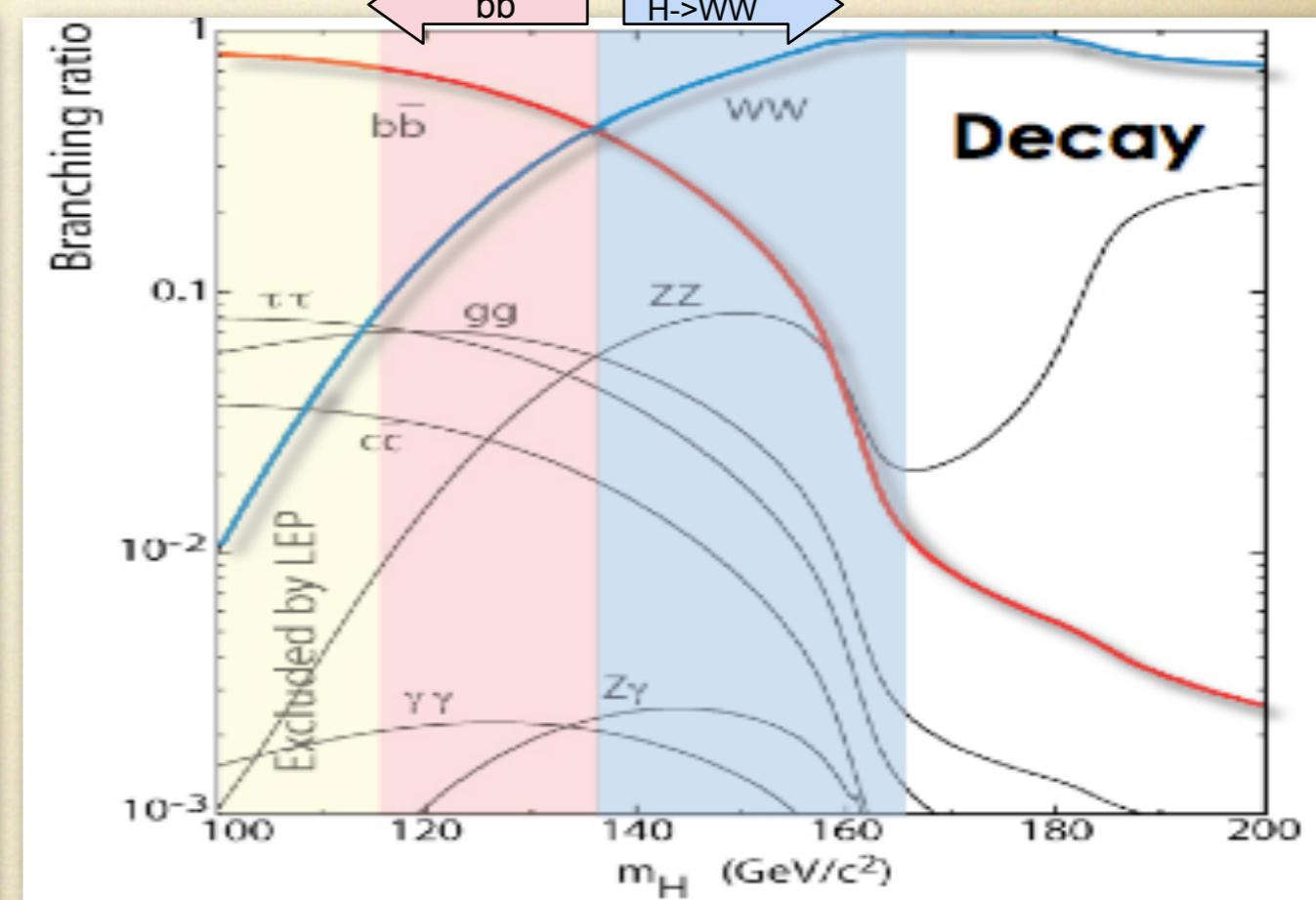
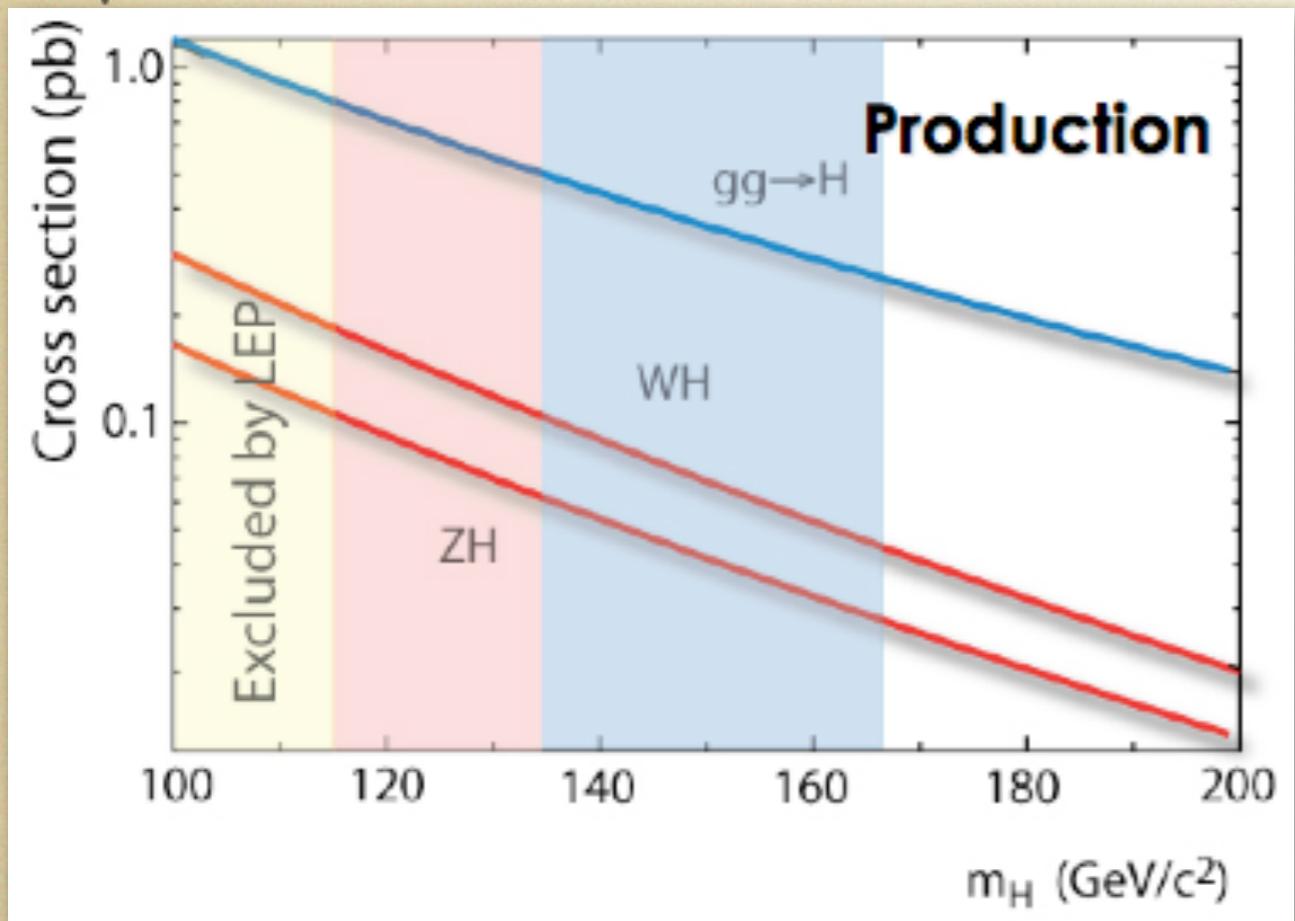
- SM Higgs is the simplest way to break EWK symmetry.
- Indirect Constraints (SM Parameters:  $M_W$ ,  $M_t$ , etc)

$$m_H = 89^{+36}_{-26} \text{ GeV/c}^2$$
$$m_H < 158 \text{ GeV/c}^2 @ 95 \% \text{ CL}$$

- Direct Searches
  - LEP:  $m_H > 114 \text{ GeV/c}^2$
  - Tevatron: Limits on Production Cross Section vs Mass.

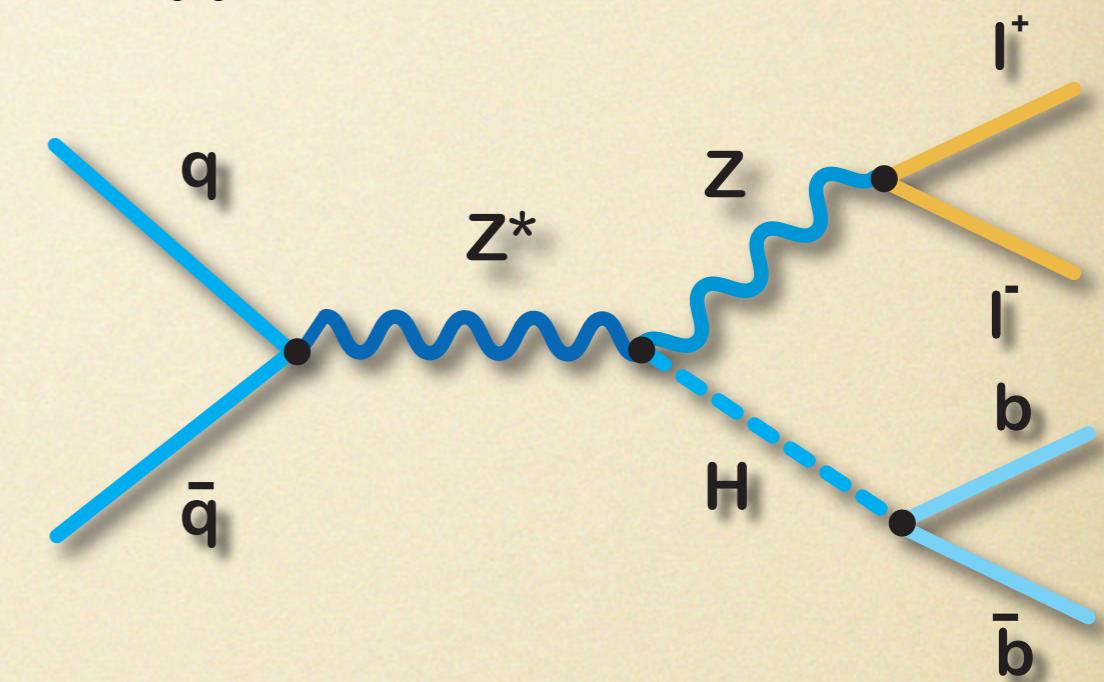
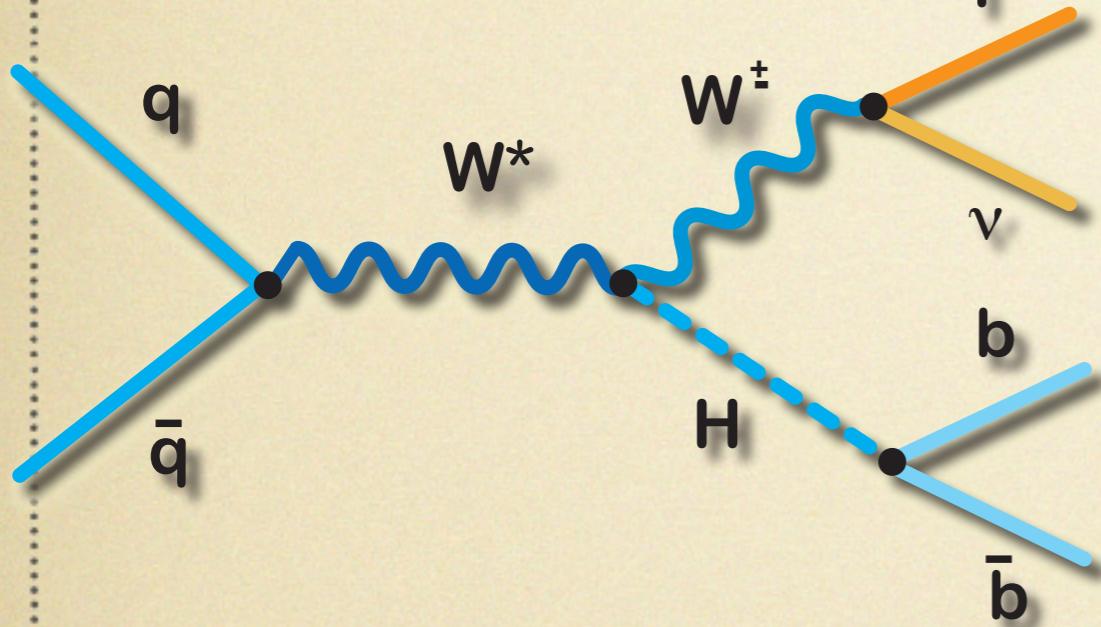


# Production and Decay



# Low Mass Final States

Primarily:  $H \rightarrow b\bar{b}$



$WH \rightarrow \ell\nu b\bar{b}$   $\rightarrow$  1 High  $P_T$  Lepton +  $E_T$  + b jets

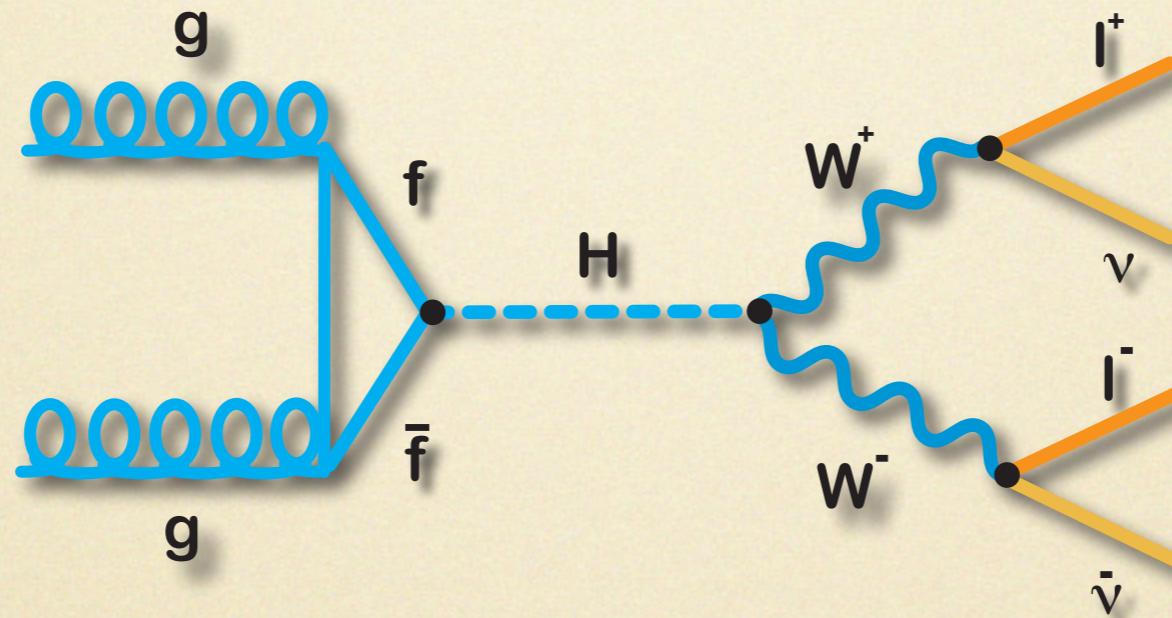
$ZH \rightarrow \ell\ell b\bar{b}$   $\rightarrow$  2 High  $P_T$  Leptons + b jets

$ZH \rightarrow \nu\nu b\bar{b}$   
 $WH \rightarrow (\ell)\nu b\bar{b}$   $\rightarrow$  0 High  $P_T$  Leptons +  $E_T$  + b jets

$VH, VBF, H \rightarrow \tau\tau + 2j$   $\rightarrow$  1 Lepton + Trk(s) + jets

# High Mass Final States

Primarily:  $H \rightarrow WW$

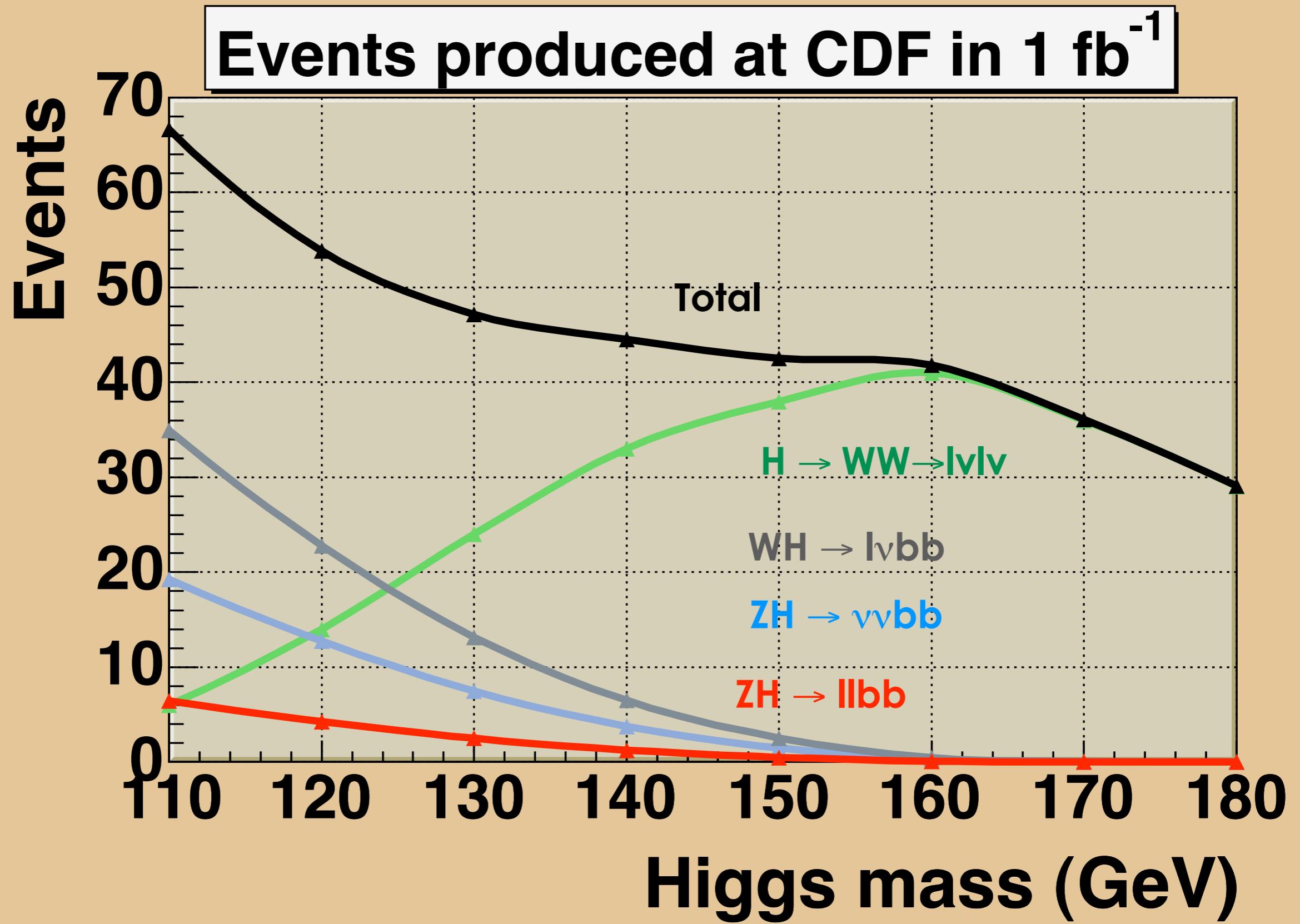


$$p\bar{p} \rightarrow H \rightarrow WW^*$$

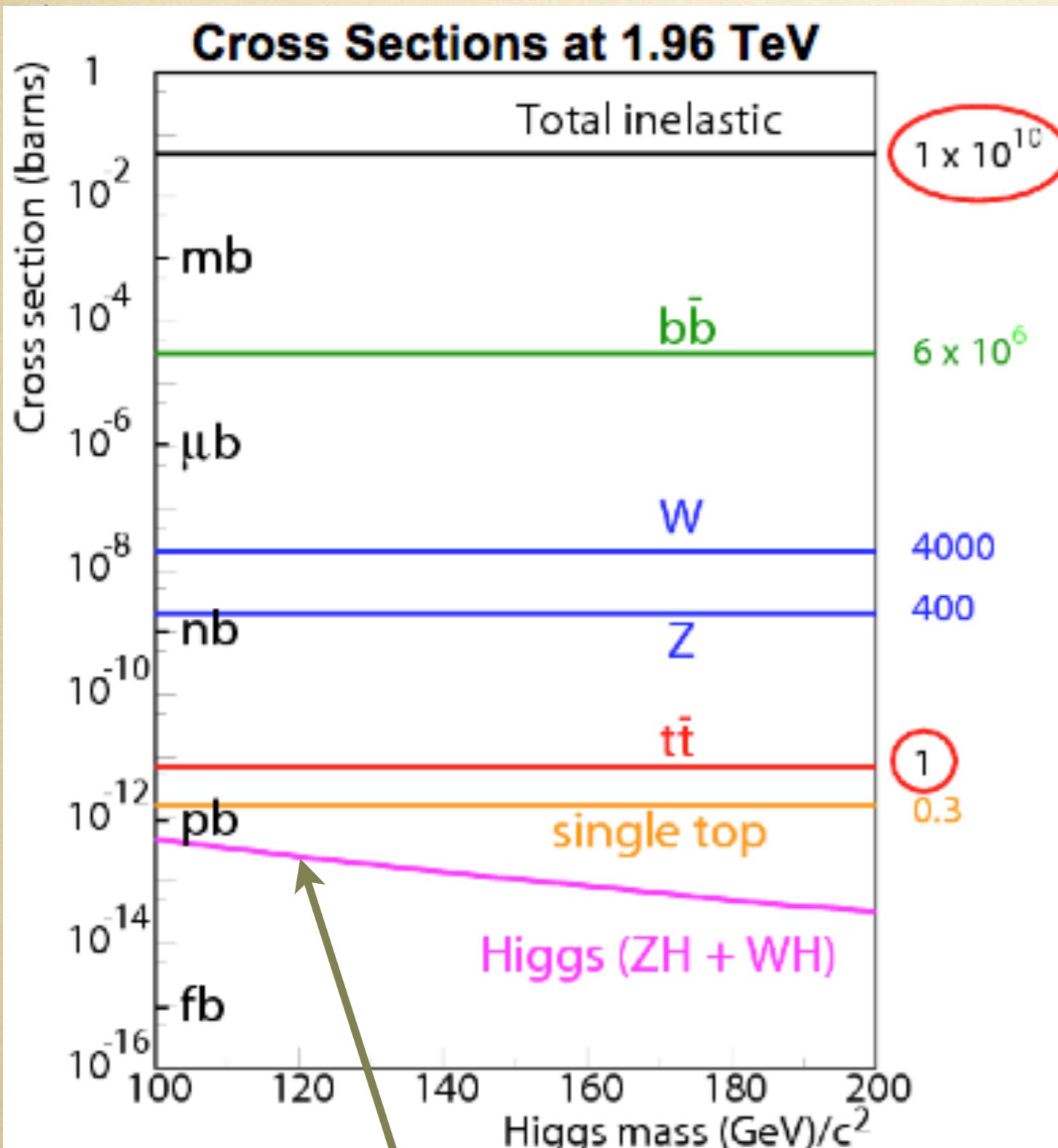
$$p\bar{p} \rightarrow VH \rightarrow VWW^*$$

Decay of W's will determine final state configuration

# Event Production



# The Challenge...



- Higgs Production is a low rate process at the Tevatron.
- Backgrounds are many orders of magnitude larger.
- Challenge:  
Separate Signal from Background

Before Anything  
 $S:B \sim 1:10^{11}$

# Analysis Approach

Searching for a small signal  
involves a multi-step process

## Key Points to Remember:

- \* Keep signal efficiency as high as possible.
- \* Eliminate Backgrounds if possible (i.e. does not lower signal efficiency much)
- \* Find ways to separate signal and remaining background to isolate high S/B regions.

# First Step...

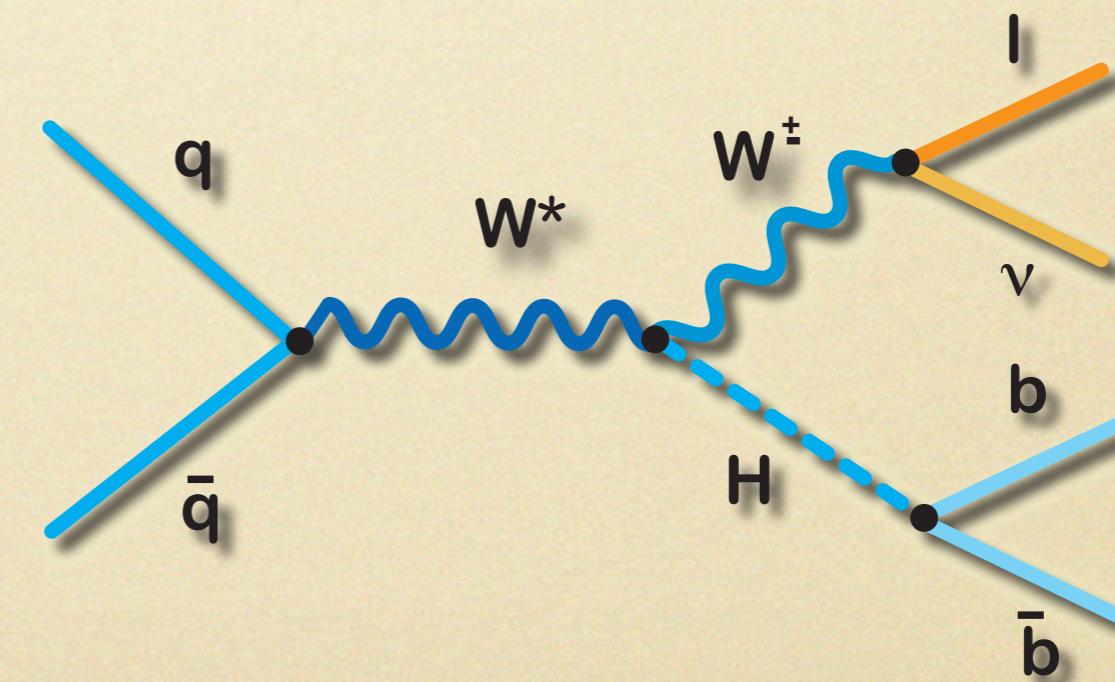
- Select High  $P_T$  leptons ( $e, \mu, \tau$ ).
- Select Events with Missing Energy (neutrino(s))
- Select Events with jets from b-quarks (low  $M_H$ )
  - variety of approaches (see next page)
- Details for each analysis slightly different

Now

$S:B_{1\text{-btag}} \sim 1:400$

$S:B_{2\text{-btag}} \sim 1:50-100$

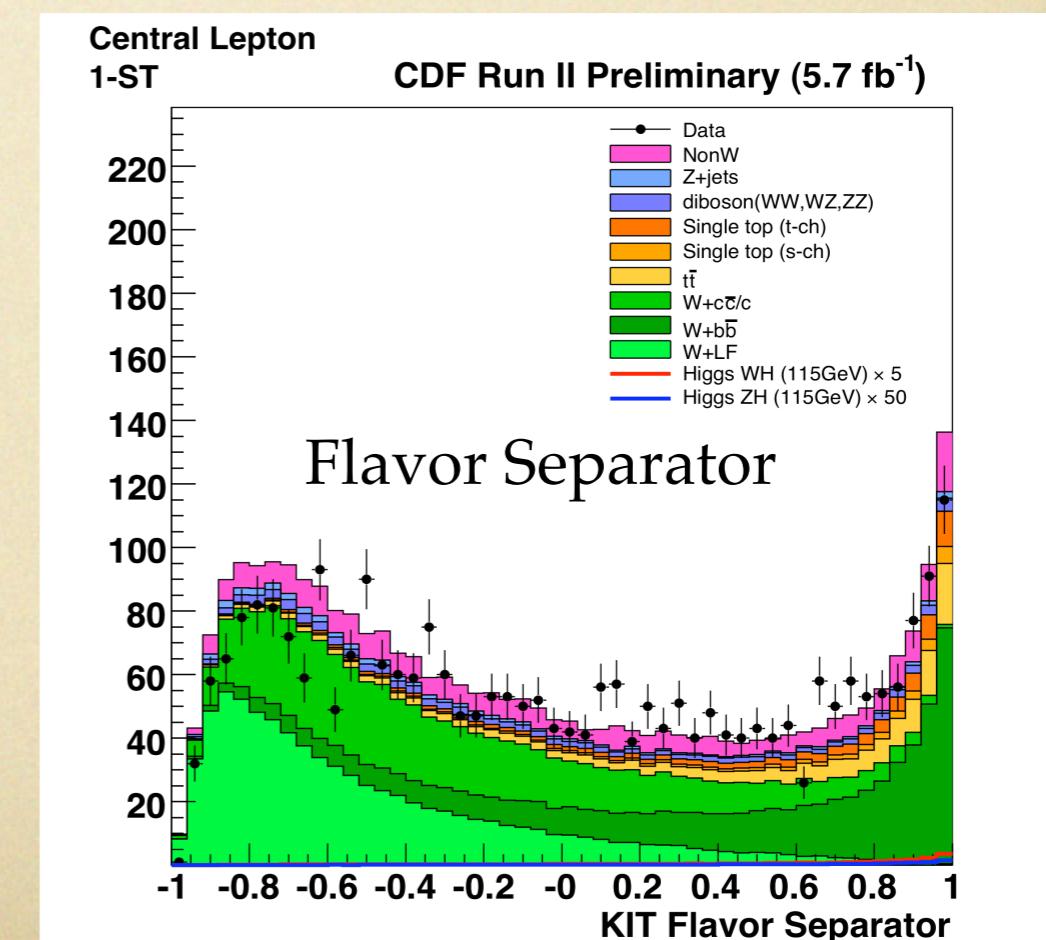
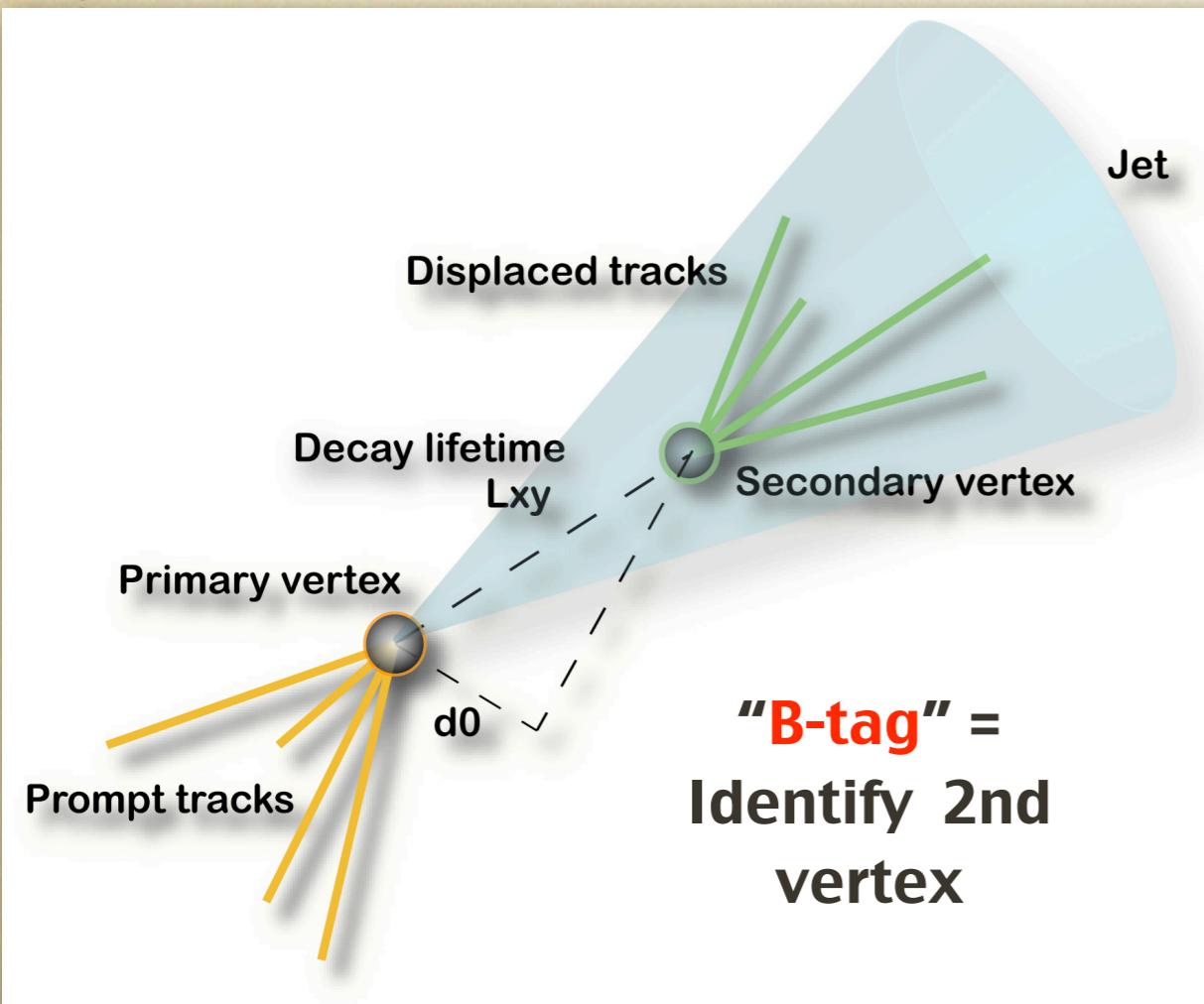
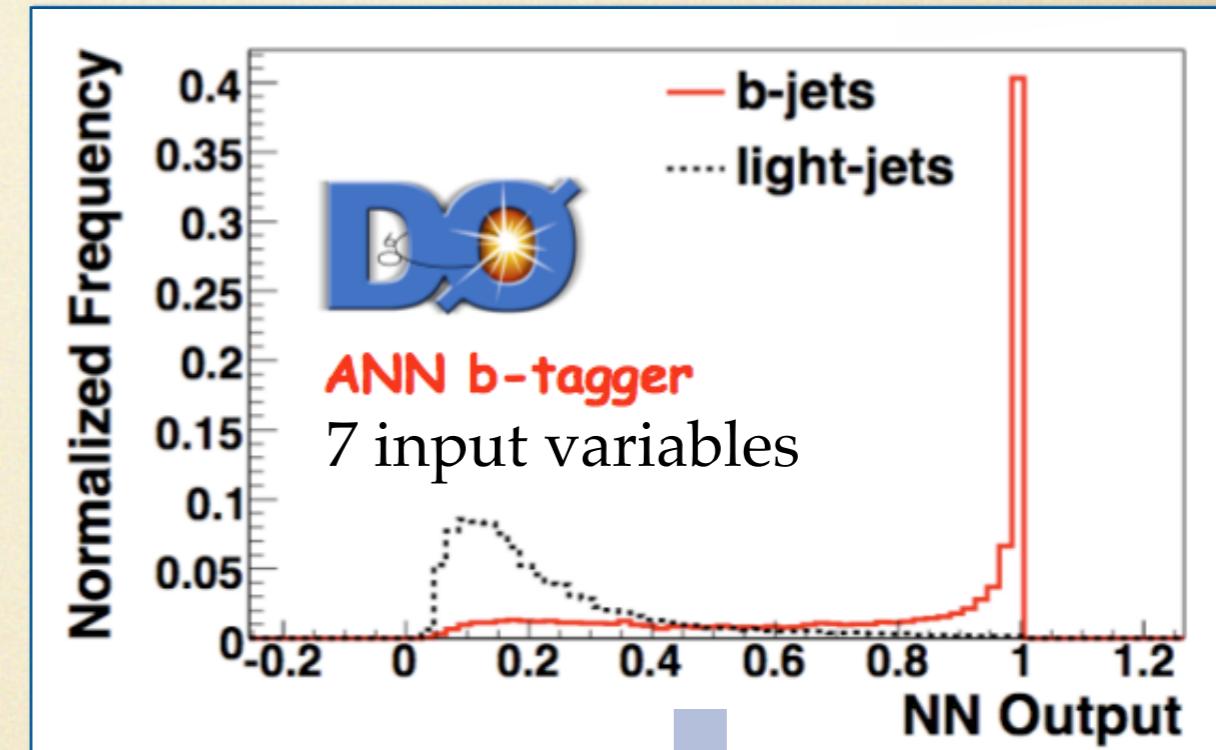
$WW \sim 1:50$



So the first factor of  
 $\sim 1$  billion is “easy”.

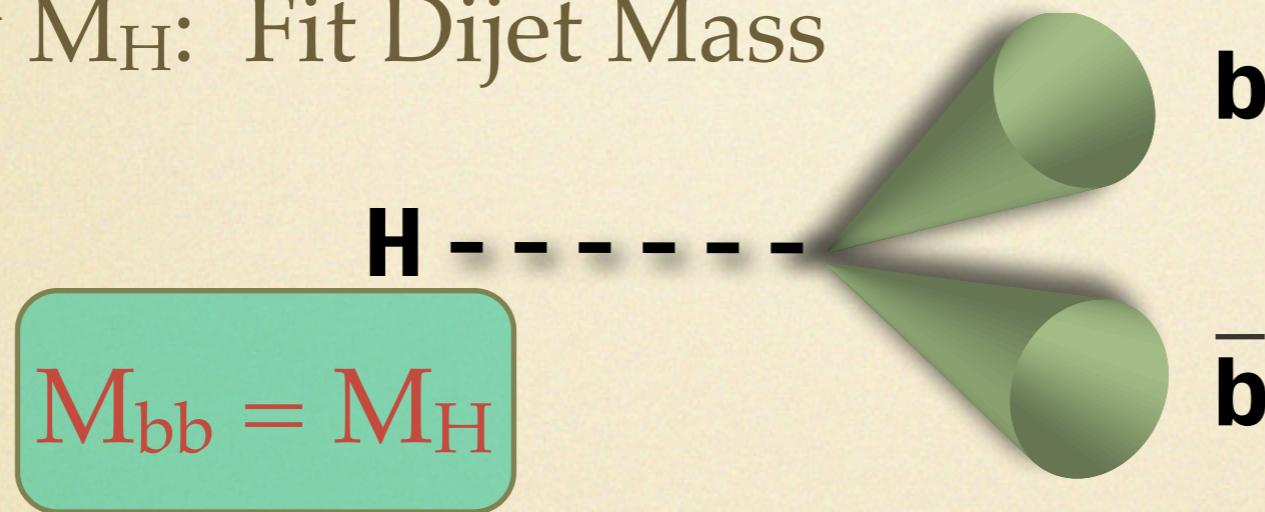
# Identify b-quark jets

- ~50-70% Efficient
  - $E_T$  and  $\eta$  dependent
- Mistag rate  $\sim 0.3\text{-}6.0\%$
- Loose tagging helpful in double tagging



# Second Step...

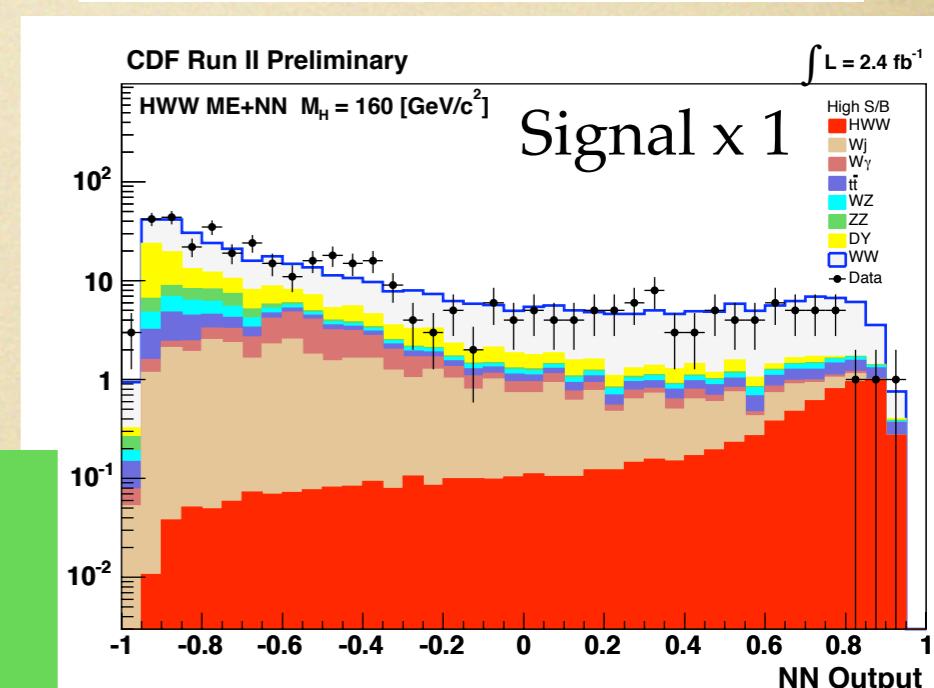
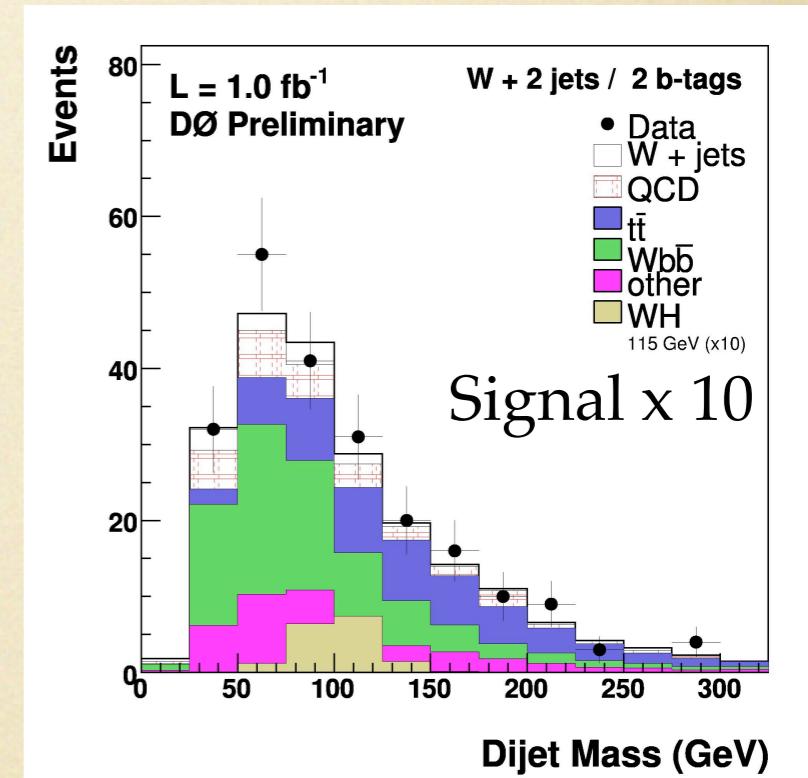
- Use other distinguishing features
- Simplest Approach: Fit a Kinematic Distribution
  - Low  $M_H$ : Fit Dijet Mass



- More Sophisticated Approach:  
**Use multivariate approach.**

- Artificial Neural Network
- Matrix Element Approach
- Other Discriminants

Important: A good discriminant gives you freedom to open up selection cuts.

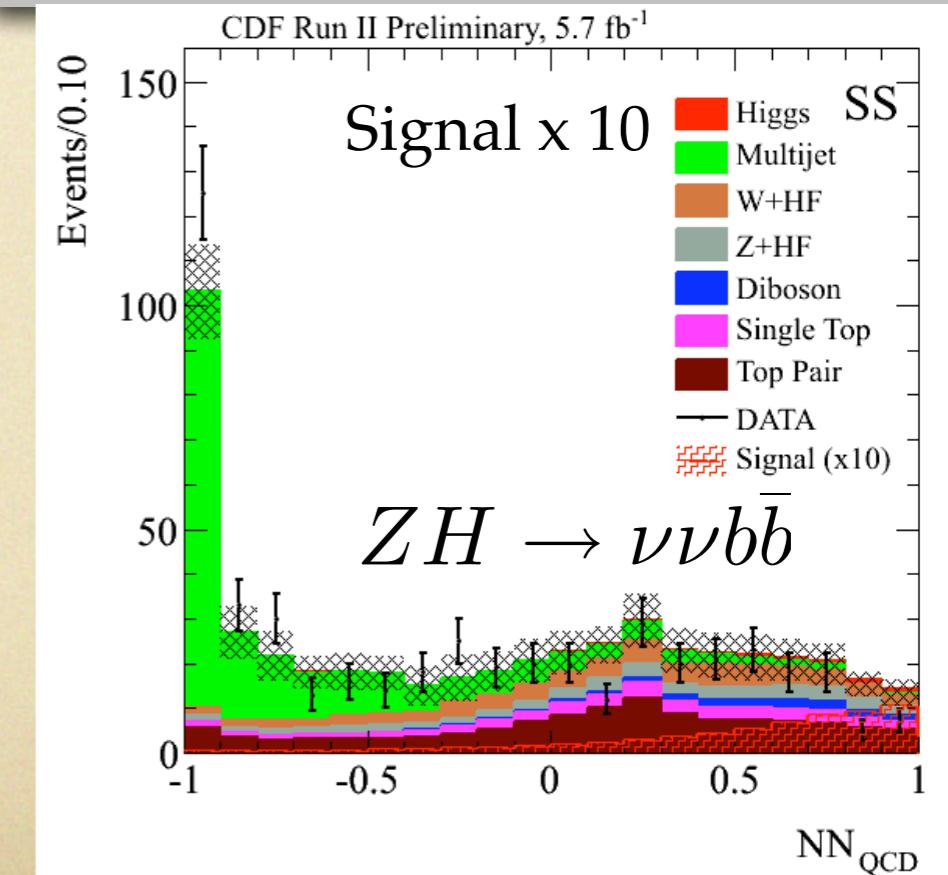


# Third Step... Optimization

- **On-going** intense optimization efforts.
- Basic Selection:
  - Maximize Trigger Configurations
  - Identify as many high  $P_T$  Leptons as possible
- B-tagging:
  - Various tagging requirements
  - **Neural Network Tagging**
- Background Rejection
- Separate different S/B samples
- Missing  $E_T$  and Jet Resolution
  - Critical for  $M_{JJ}$  Resolution
  - Multivariate Inputs

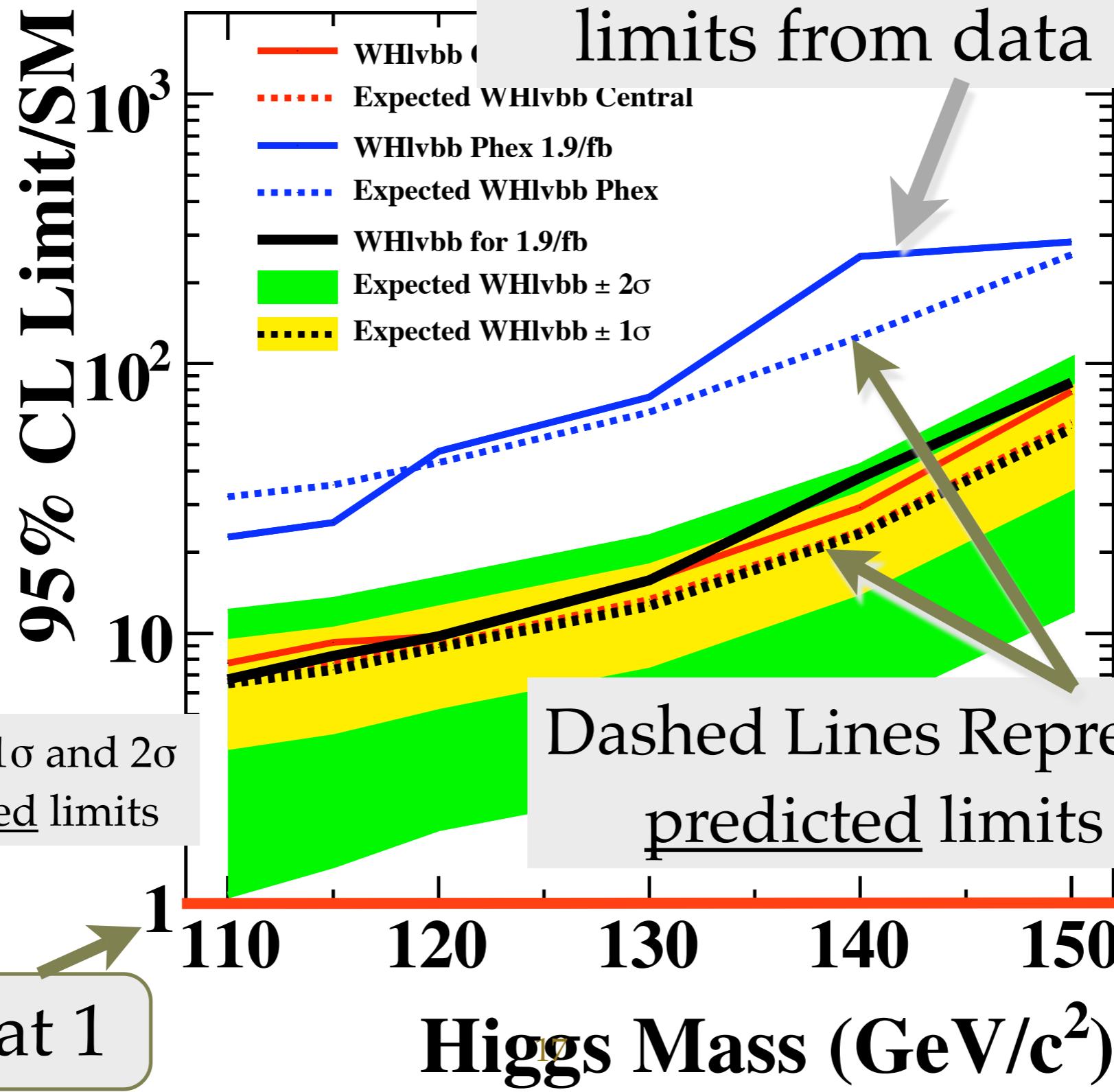
**This is the  
hard work!**

e.g. Multijet Removal



# Decoding Limit Plots 101

Solid Lines represent observed limits from data analysis.



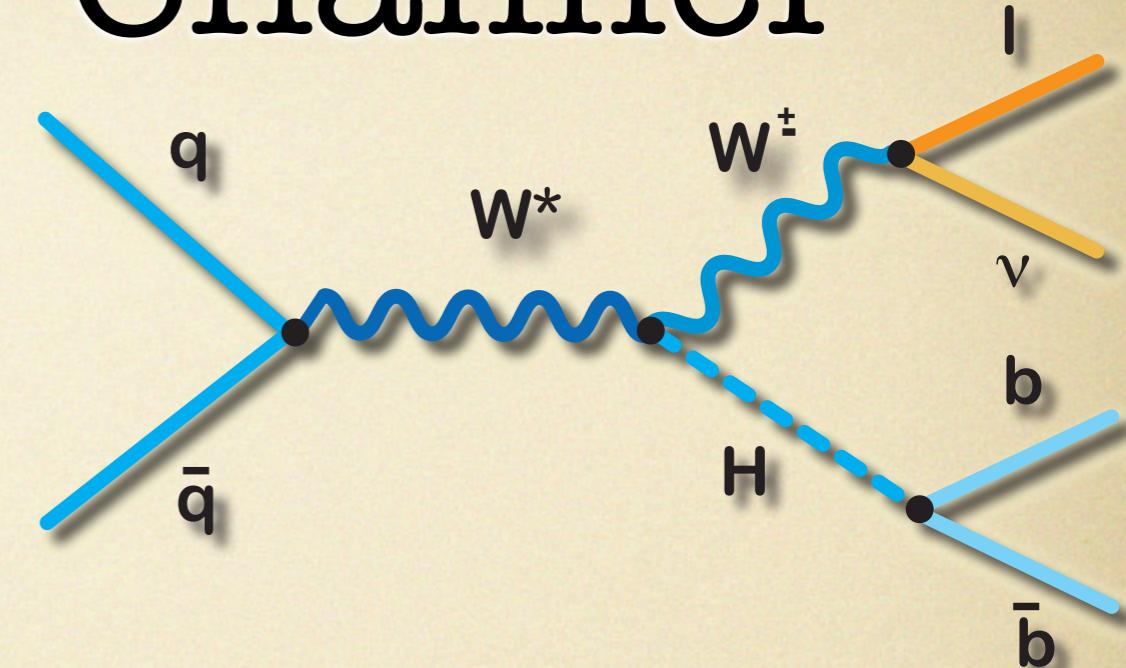
# Low Mass Signatures

# $WH \rightarrow \ell\nu b\bar{b}$ Channel

- High  $P_T$  e or  $\mu$
- Missing  $E_T$
- 2 jets
- Split up 1 and 2 b-tags
- Examine “Figures of Merit”

## Features:

1. Good Acceptance
2. Final state similar to single top prod.
3.  $\sim 2\text{-}3 \text{ evts/fb}^{-1}$



## Primary Backgrounds

- $Wb\bar{b}$ ,  $Wc\bar{c}$ ,  $Wqq'$
- $t\bar{t}$
- Single top
- non-W QCD
- $WZ$ ,  $WW$
- $Z \rightarrow \tau\tau$

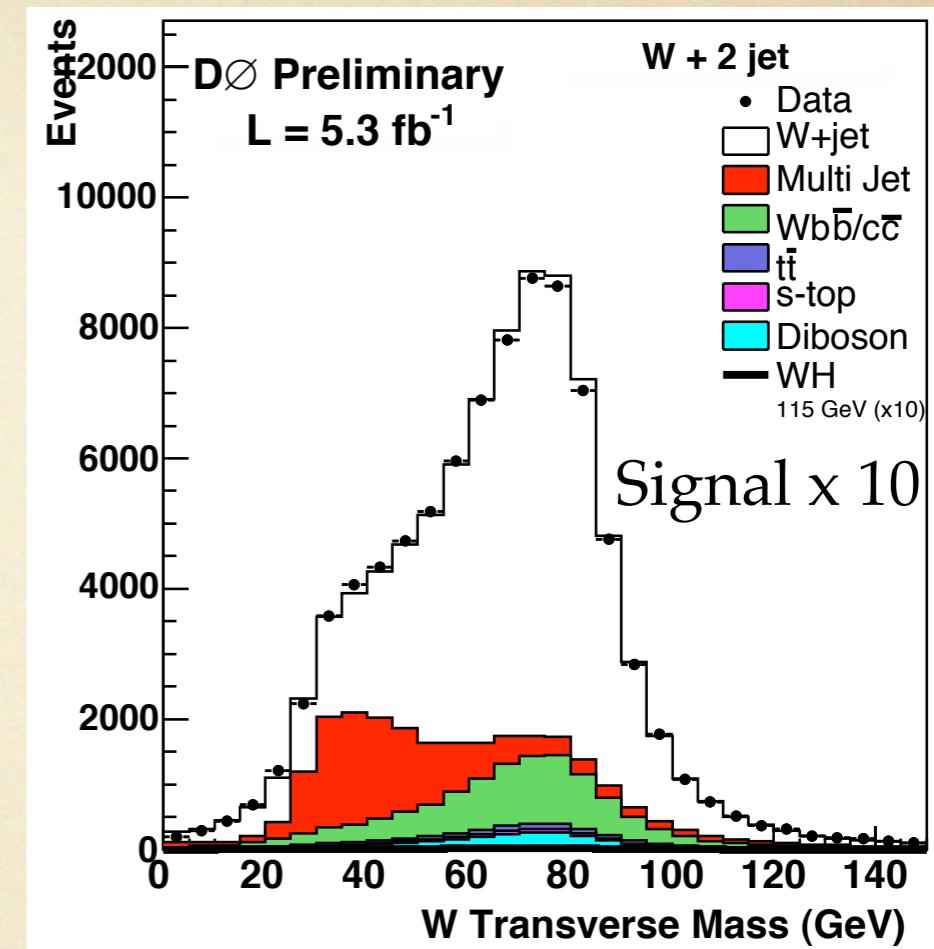
# $WH \rightarrow \ell\nu b\bar{b}$

## Approach



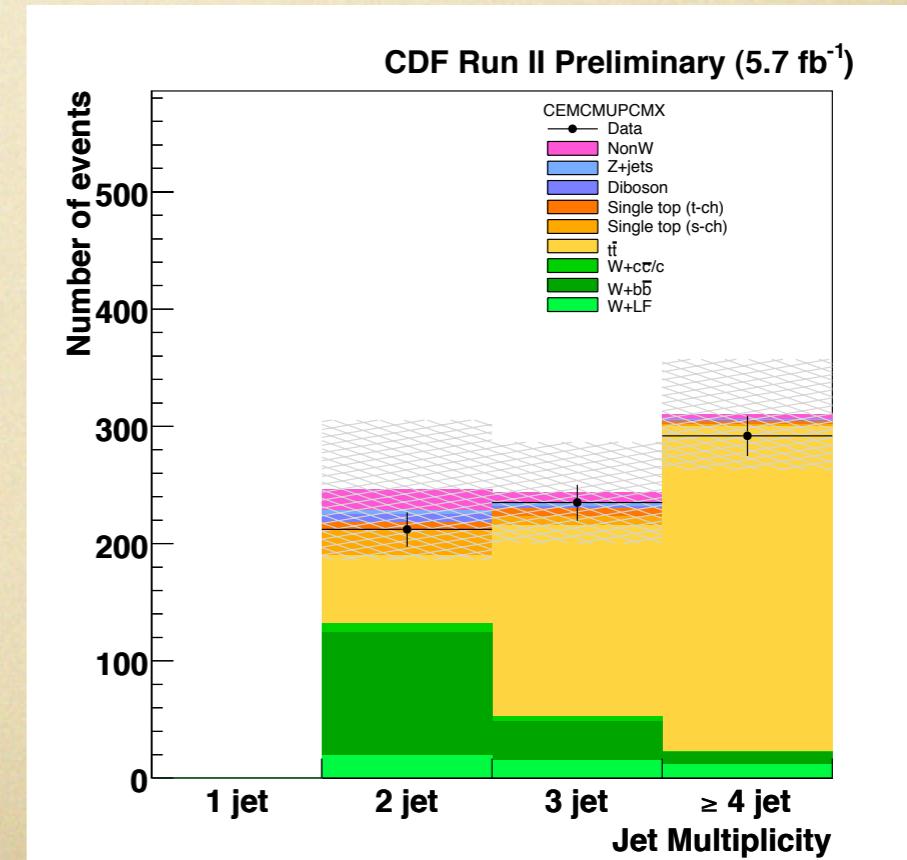
D0 method:

- e/ $\mu$  MET, 2/3 jets
- Double loose or single tight tagging
- Random forest discriminant



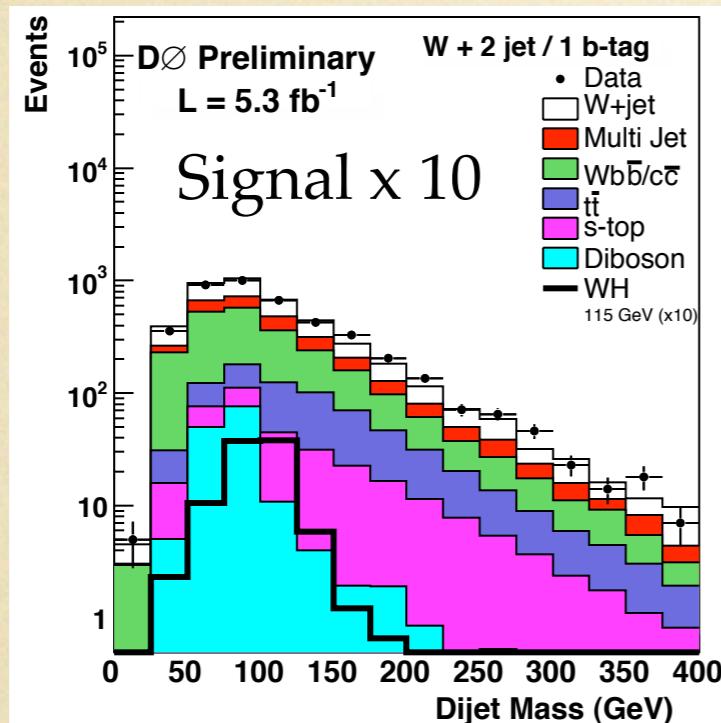
CDF uses 2 methods:

- e/ $\mu$  MET, 2/3 jets
- double loose or single tight tagging
- Flavor separator for single tags
- Two discriminants
  - 1) Matrix Element
  - 2) Bayesian Neural Network (adds in single isolated tracks as well)

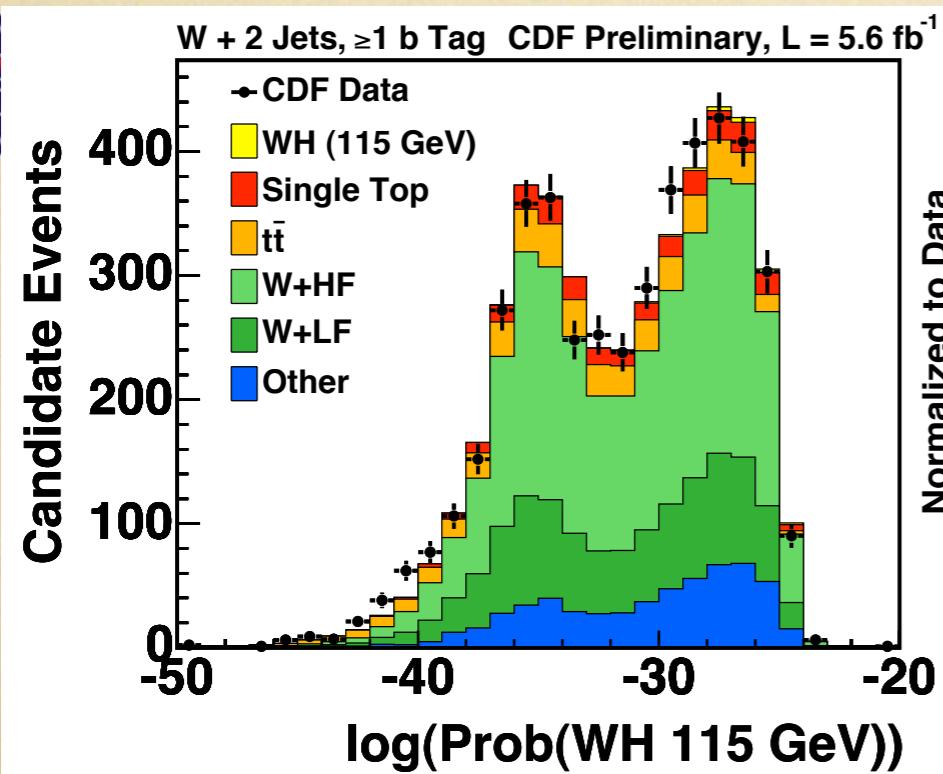
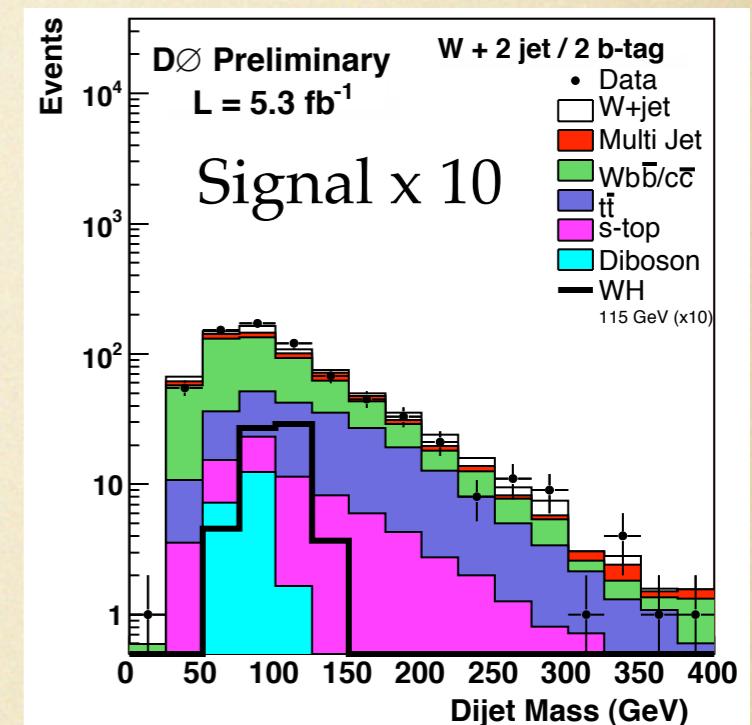


$WH \rightarrow \ell\nu b\bar{b}$

# Discriminant Inputs



Random Forest of decision trees uses 18 different kinematic variables.

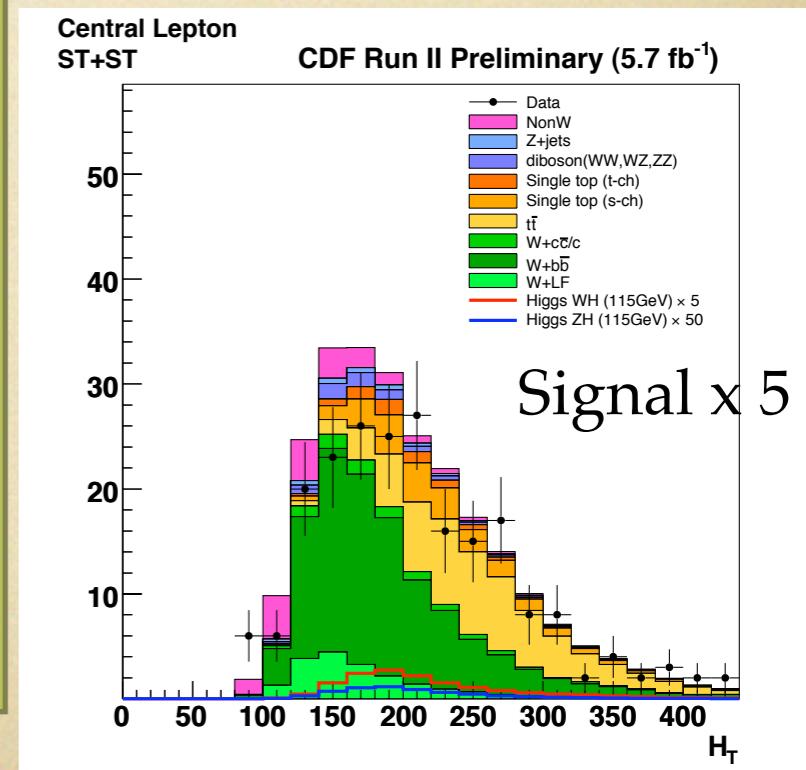


Typical NN Inputs

$M_{jj}$     $P_T^{imb}$     $M_{max}^{\ell\nu j}$   
 $Q \times \eta_{lep}$   
 $\sum E_T^{loose j}$     $P_T^W$     $H_T$

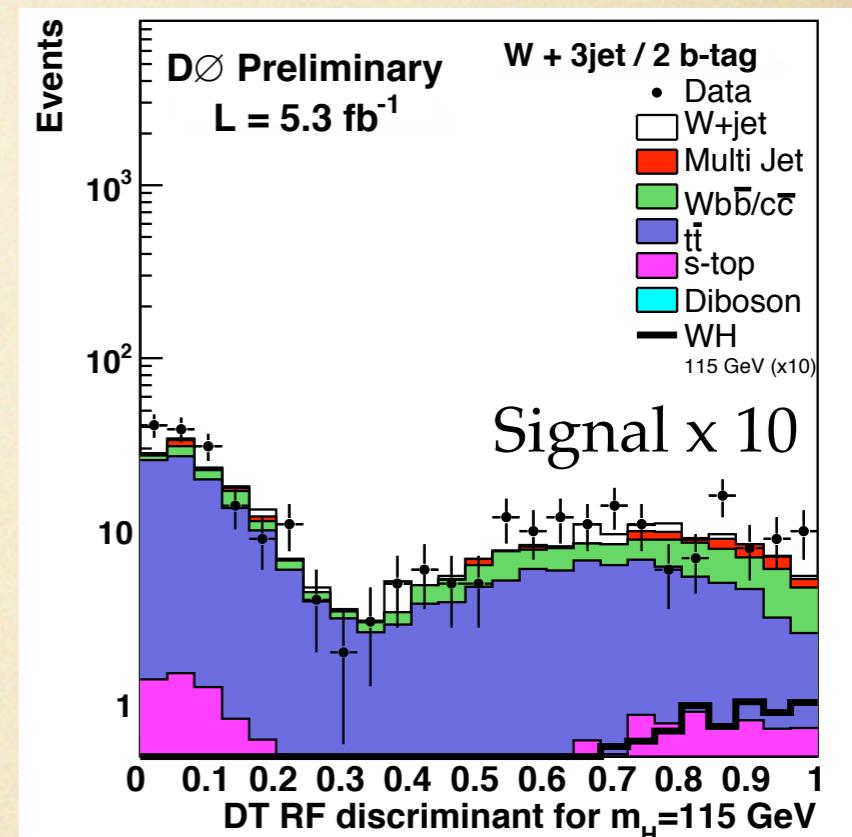
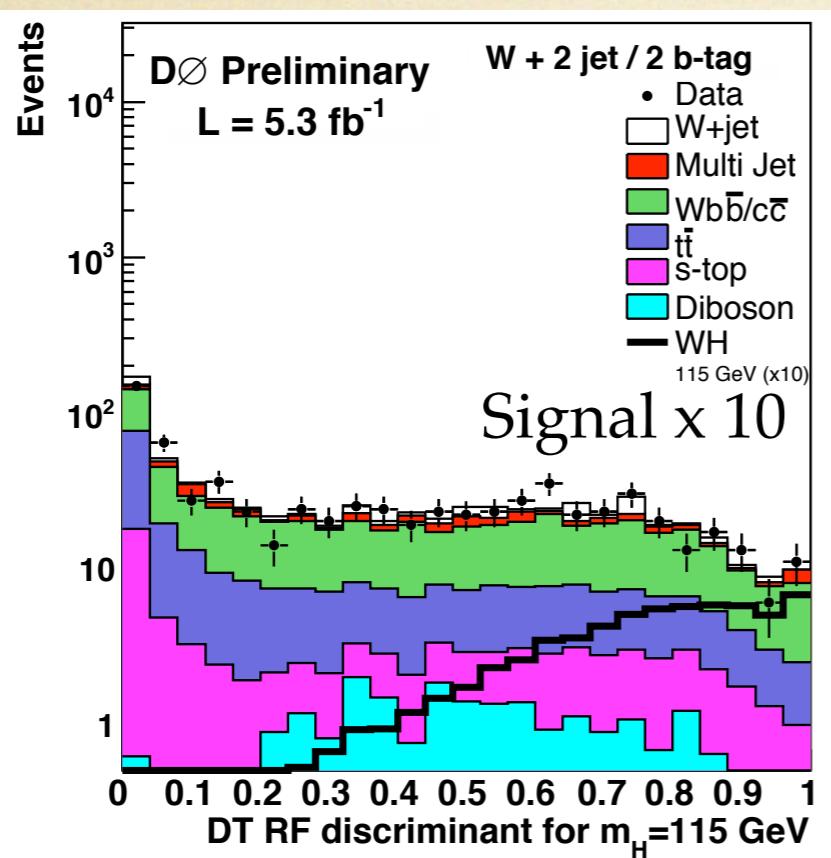
Each subchannel optimized => slightly different inputs

21

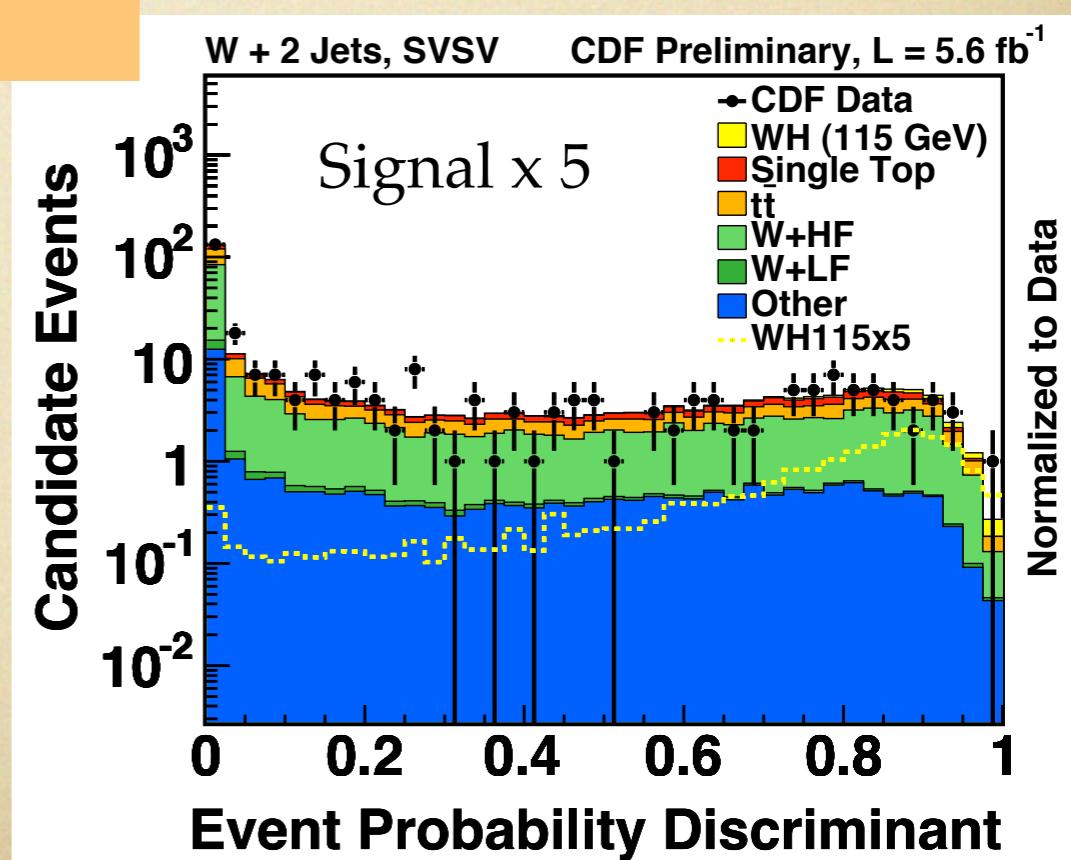
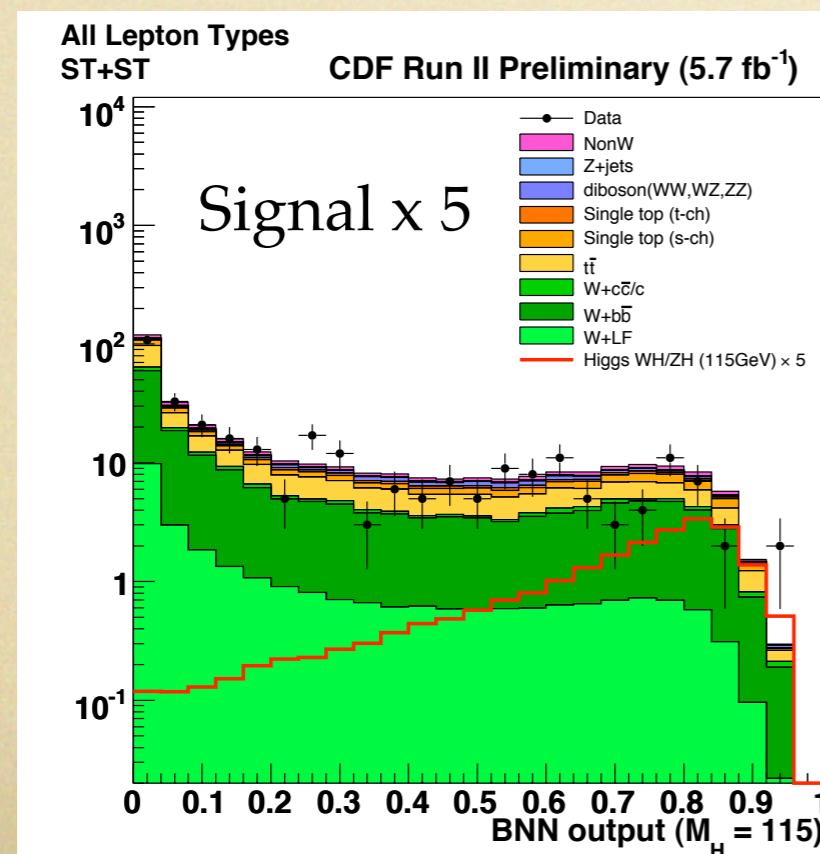


$WH \rightarrow \ell\nu b\bar{b}$

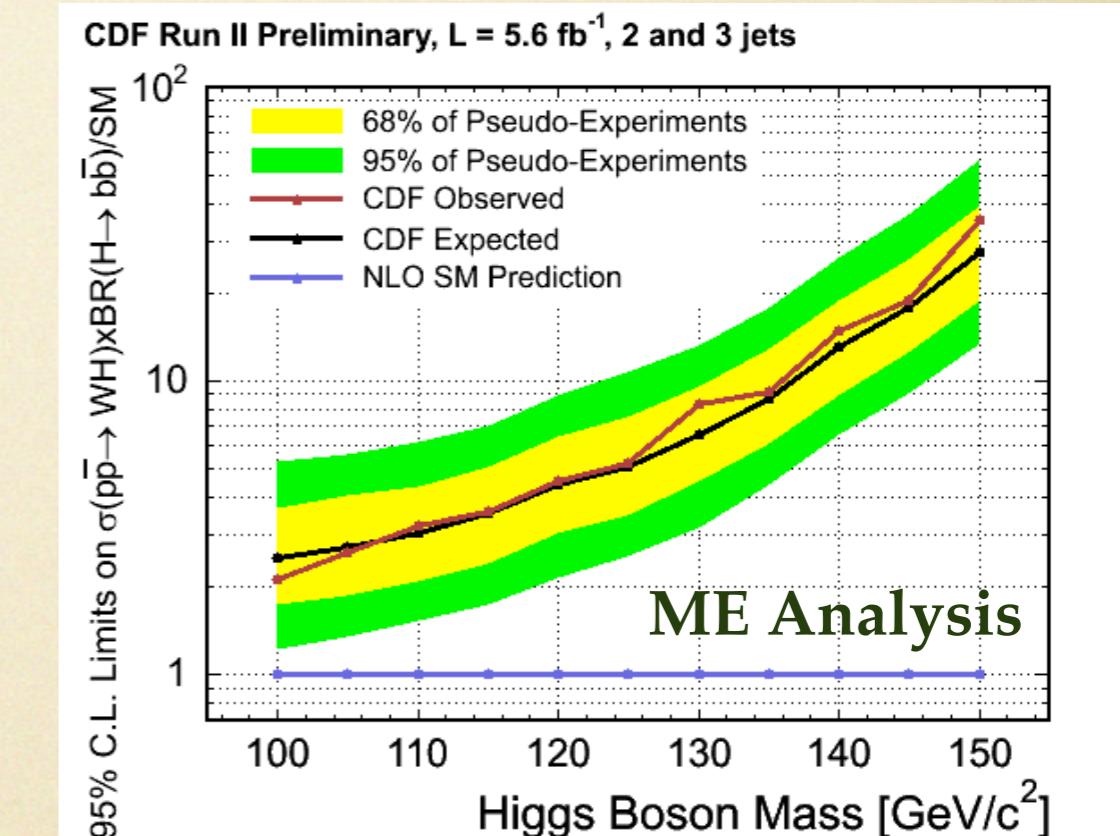
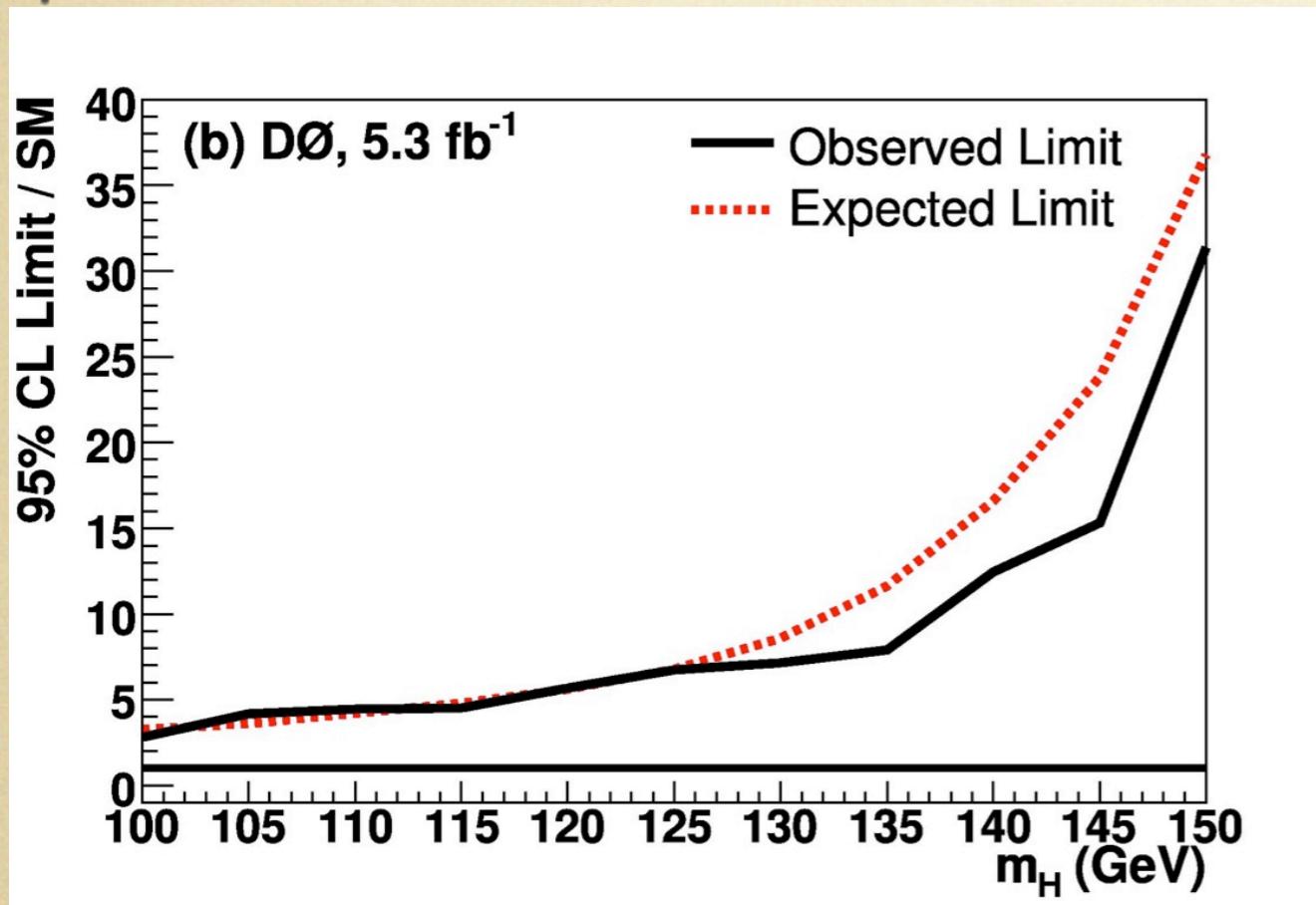
# Final Discriminants



Best subchannels;  
others contribute  
as well



# $WH \rightarrow \ell\nu b\bar{b}$ Limits

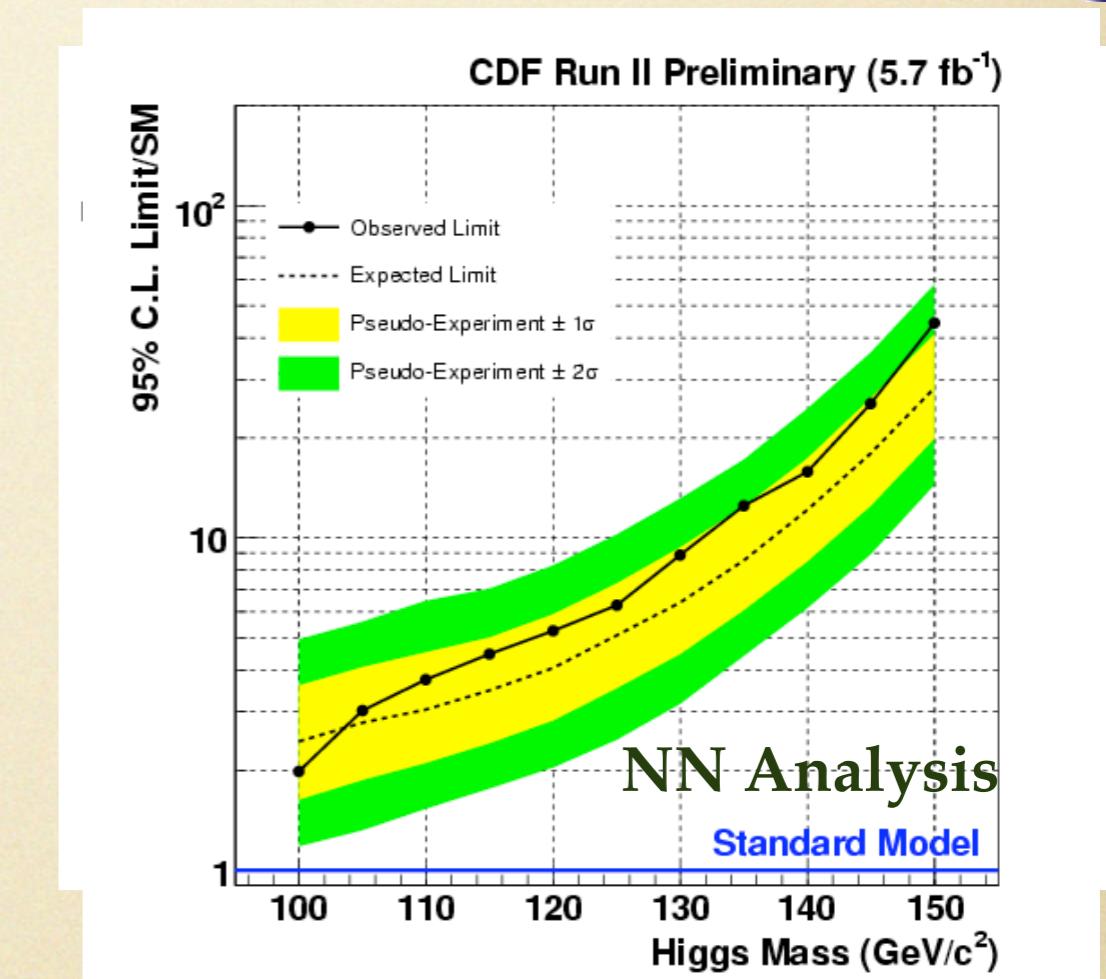
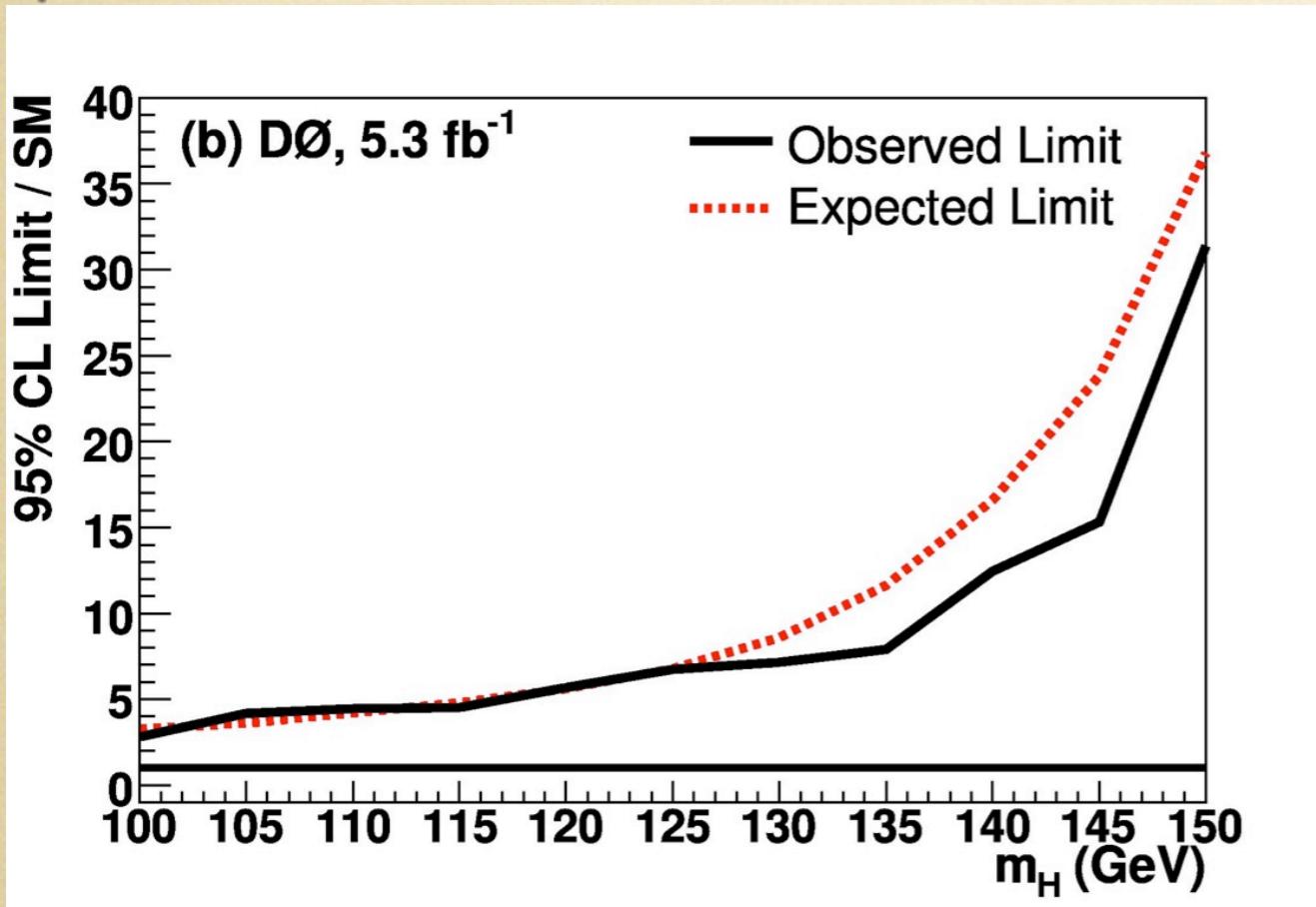


Subchannels  
combined.

Experiment	Lum	Obs/SM	Exp/SM
D0	$5.3 \text{ fb}^{-1}$	4.5	4.8
CDF	$5.7 \text{ fb}^{-1}$	3.6/4.5	3.5/3.4

$$M_h = 115 \text{ GeV}/c^2$$

# $WH \rightarrow \ell\nu b\bar{b}$ Limits



Subchannels  
combined.

Experiment	Lum	Obs/SM	Exp/SM
D0	$5.3 \text{ fb}^{-1}$	4.5	4.8
CDF	$5.7 \text{ fb}^{-1}$	3.6/4.5	3.5/3.4

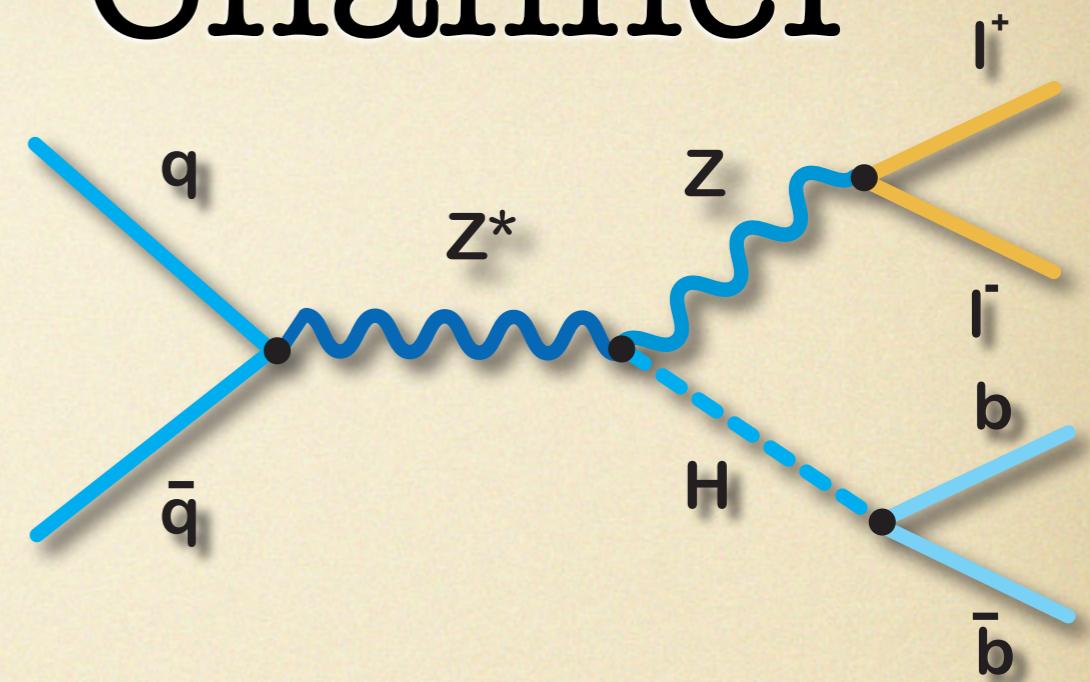
$$M_h = 115 \text{ GeV}/c^2$$

# $ZH \rightarrow \ell\ell b\bar{b}$ Channel

- Two High  $P_T$  ee or  $\mu\mu$
- No (direct) Missing  $E_T$
- 2 jets
- Split up 1 and 2 b-tags

## Features:

1. Small  $\sigma \cdot BR$
2. Several tight constraints
  - i.  $M_{ll} \approx M_z$
  - ii. “ $\cancel{E}_T$ ”  $\rightarrow$  improve jet resol.
3.  $\sim 1$  evt/fb $^{-1}$



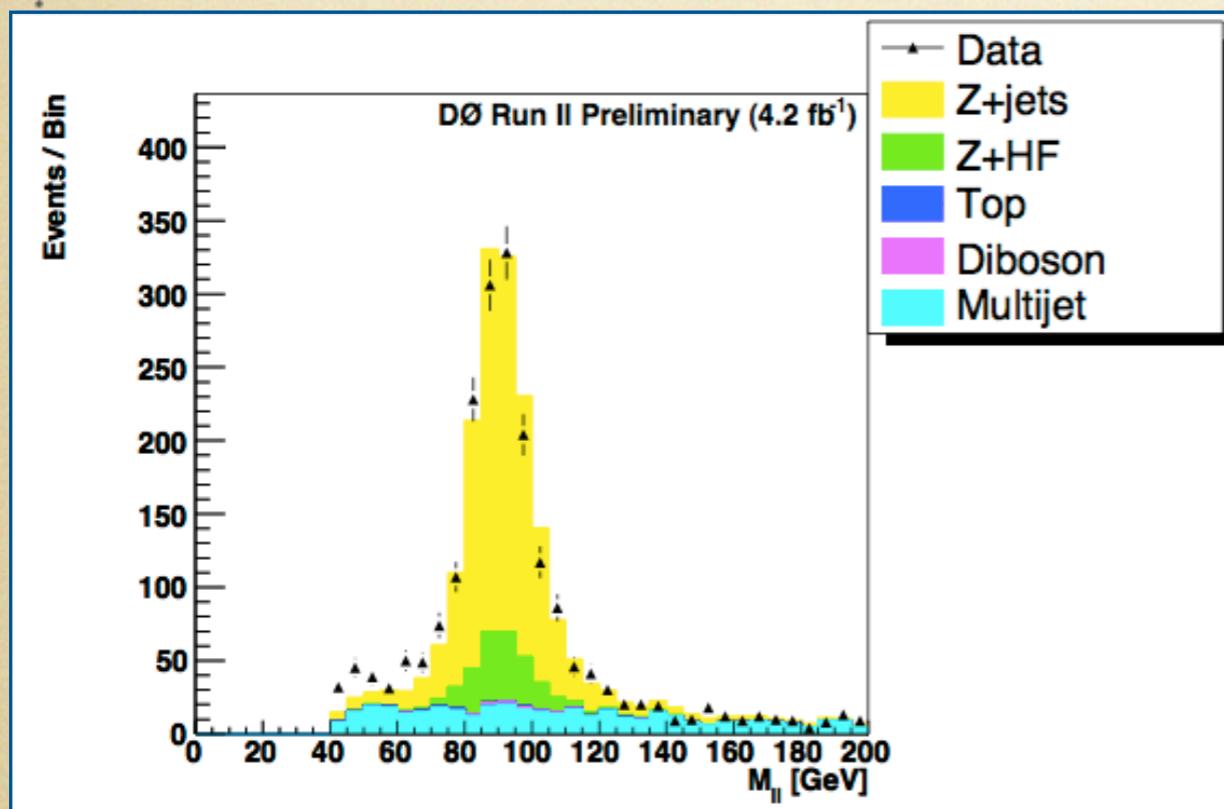
## Primary Backgrounds

$Zb\bar{b}$ ,  $Zc\bar{c}$ ,  $Zqq'$   
 $t\bar{t}$   
 $WW + jj$ ,  $WZ$ ,  $ZZ$   
 $Z \rightarrow \tau\tau$

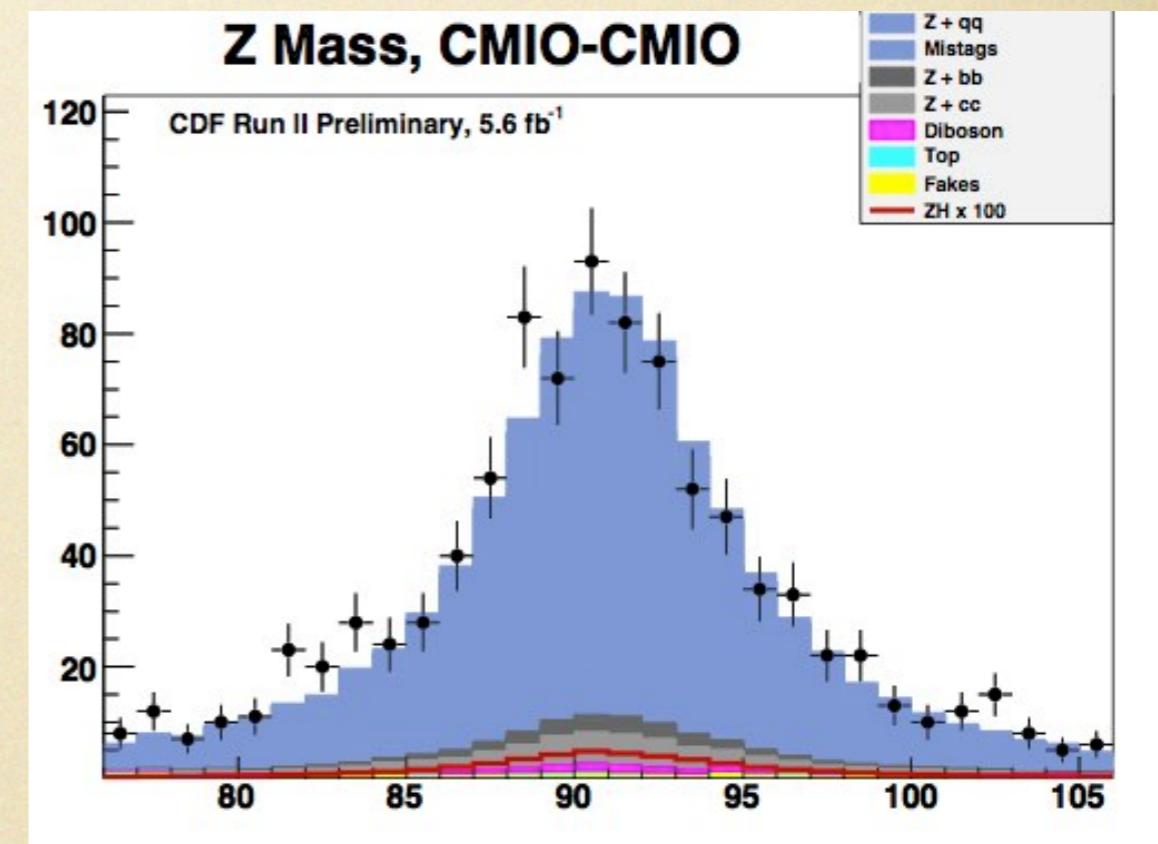
# Maximizing Acceptance

Example: Find more Z decays

Reconstruct Z candidate  
using a  $\mu$  and an  
isolated track



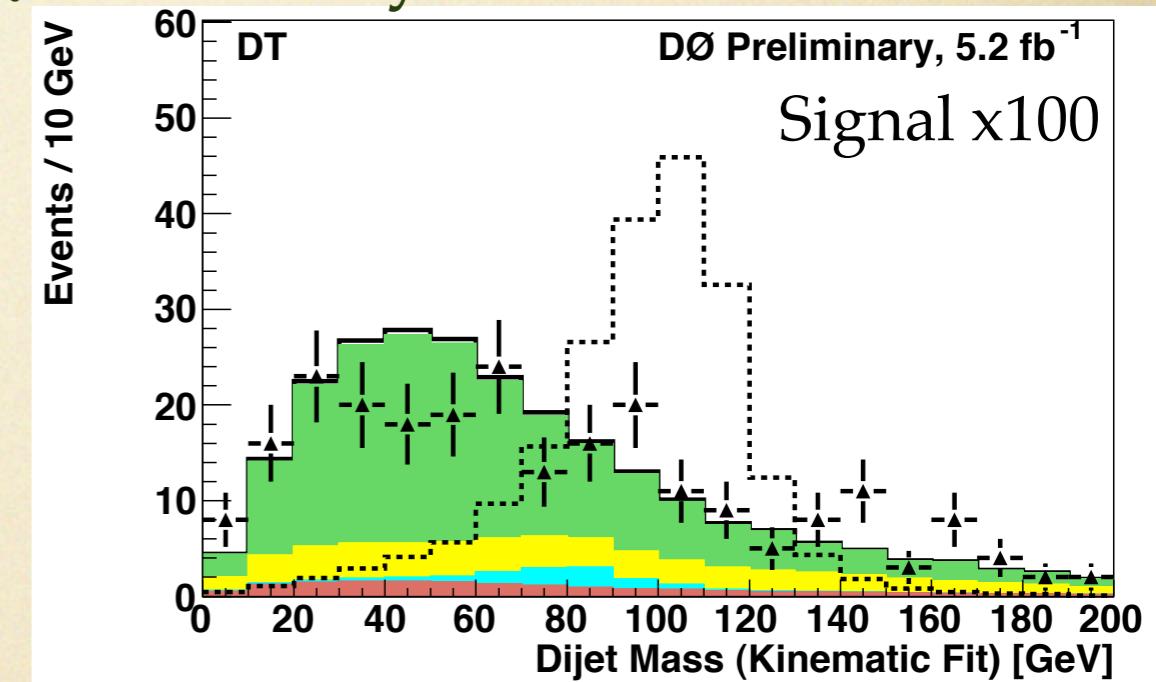
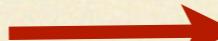
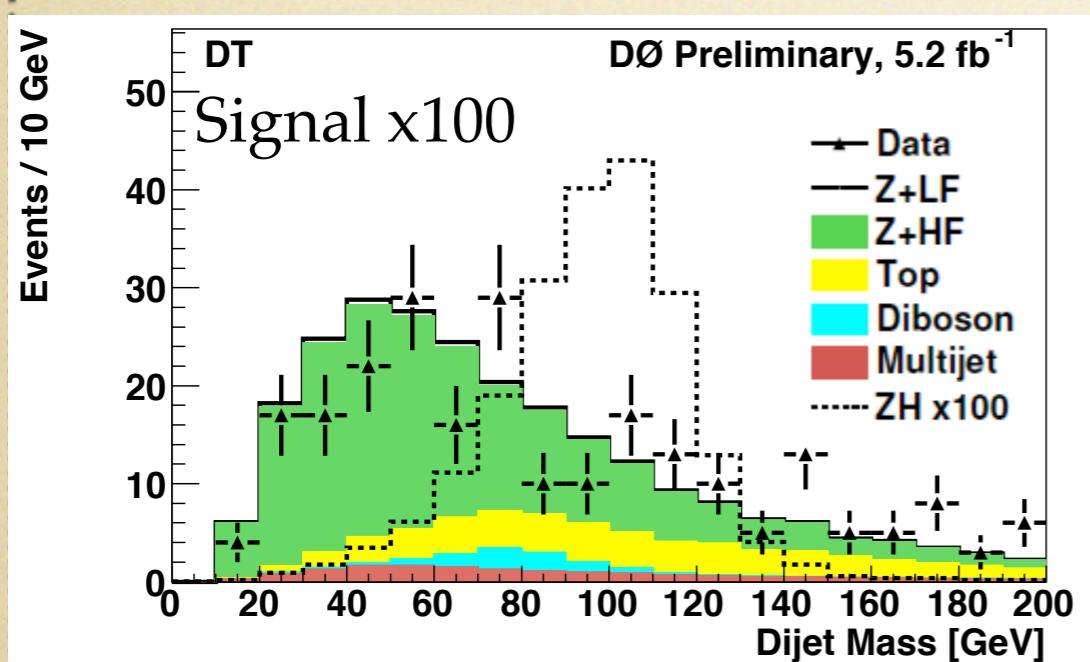
Reconstruct Z candidate using  
two loose muons AND non-  
muon trigger!



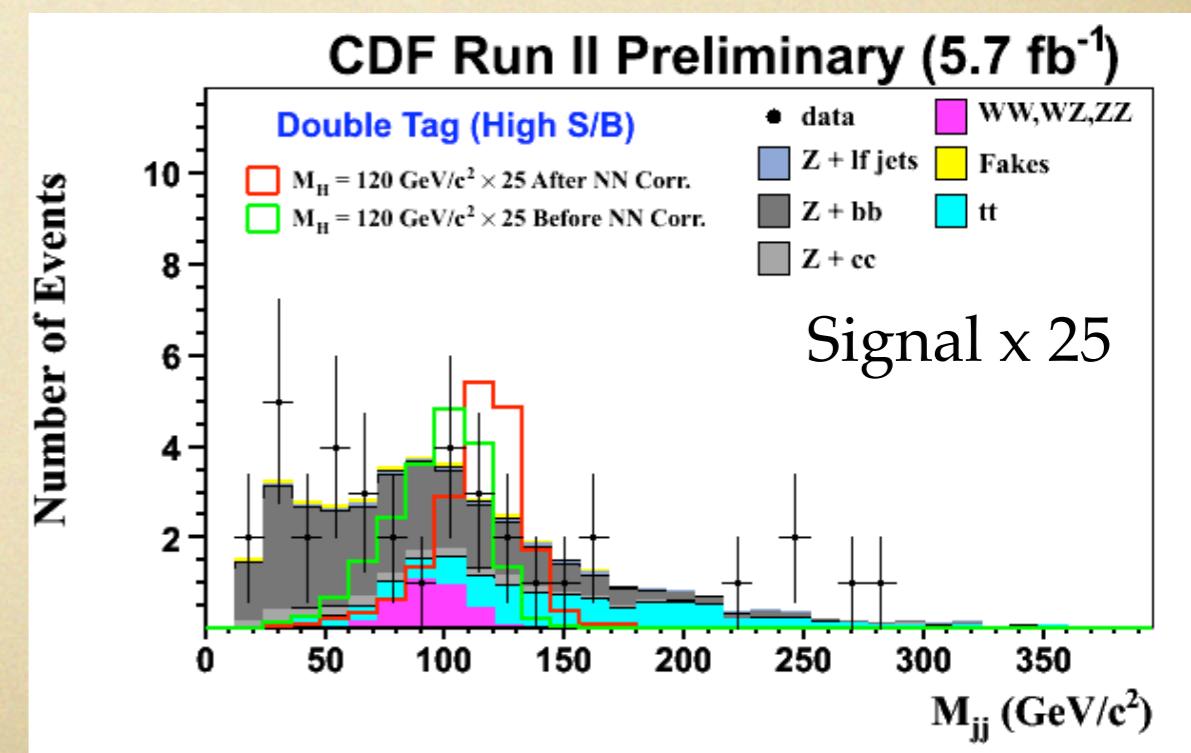
Typical gain from increased lepton ID  
 $\sim 15\%$

# optimize reconstruction

Example: Improve dijet mass resolution  
 D0 uses a kinematic fit, adjusting lepton and jet energies  
 to obtain the correct  $M_z$  and  $P_t$  of the llbb system



CDF uses a NN, with inputs of observed jet energies and directions, MET magnitude and direction, to correct the two highest Et jets

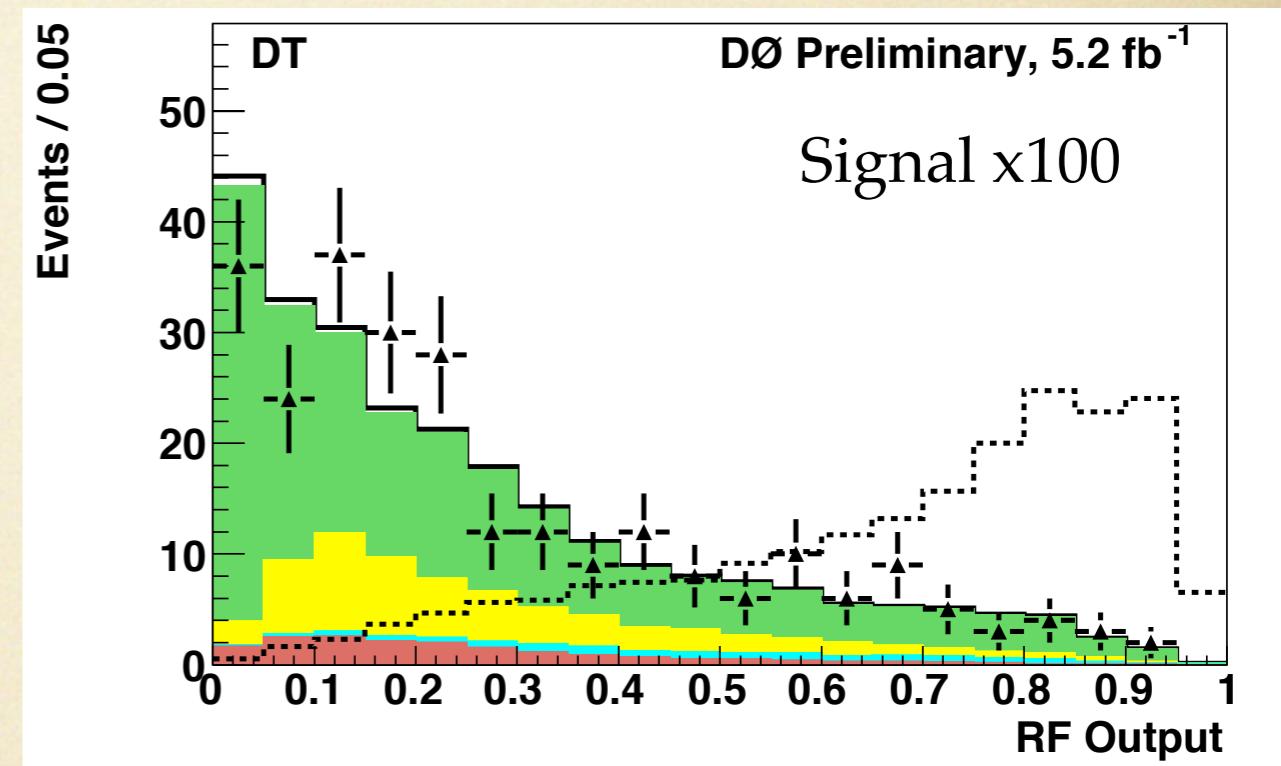


# $ZH \rightarrow \ell\ell b\bar{b}$ Discriminants



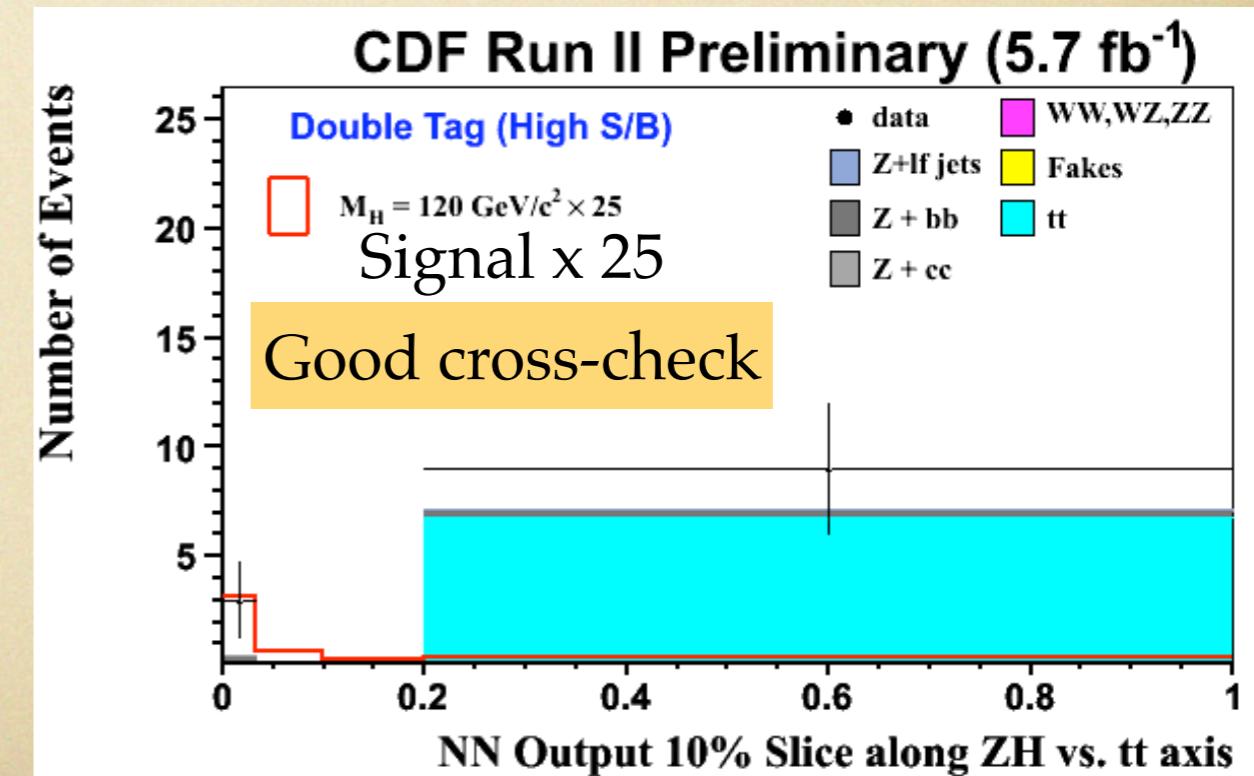
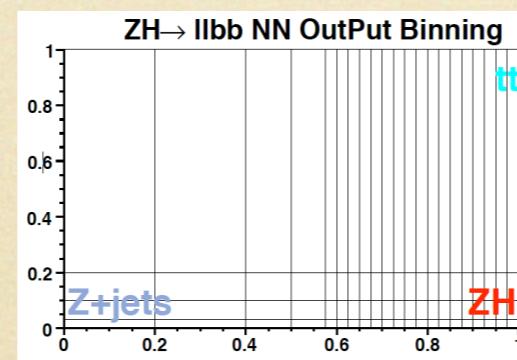
D0 uses a Random Forest Decision Tree method:

- 20 well modeled inputs chosen
- 200 trees are trained, using a random subset of 10 inputs
- RF Output is the performance weighted result of all 200 trees

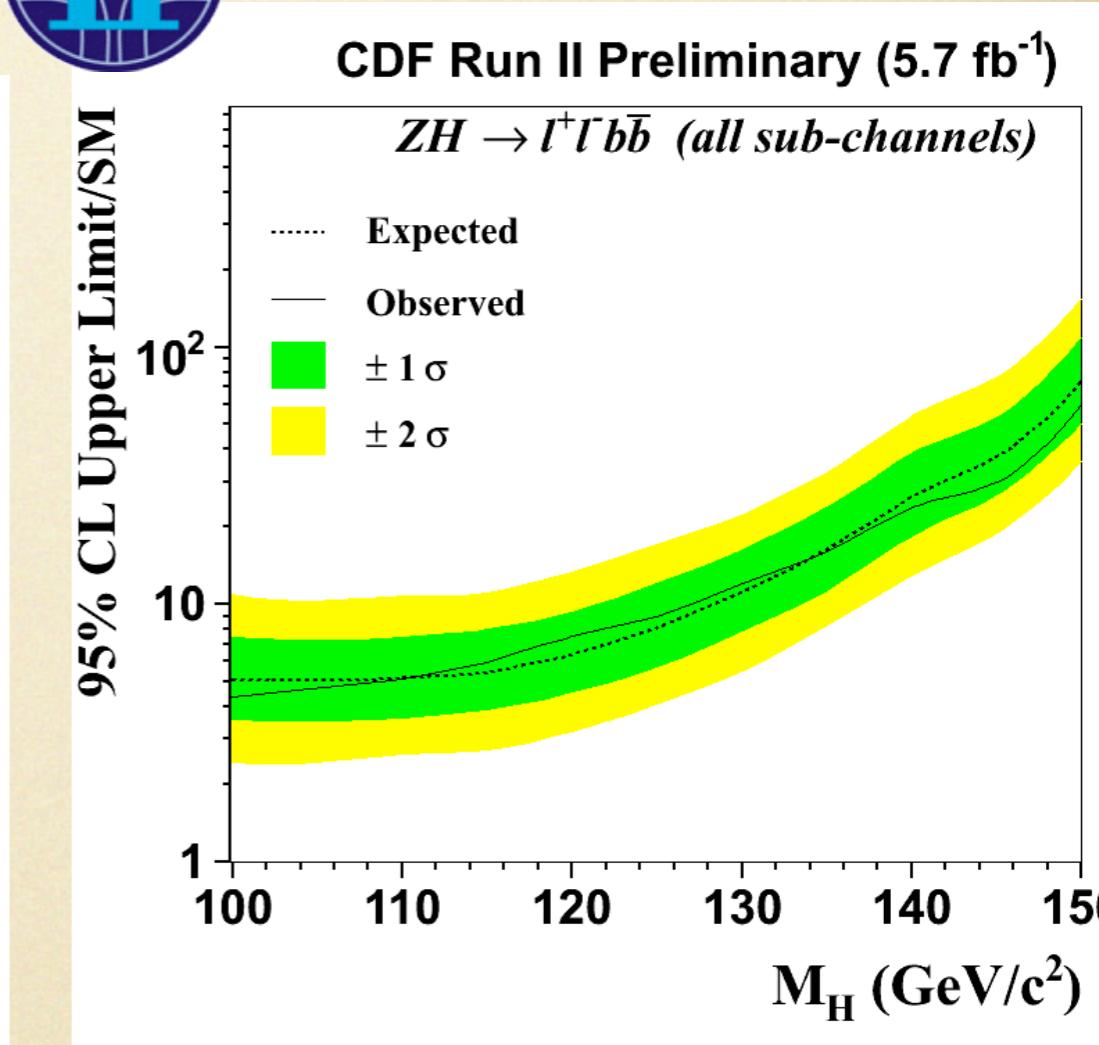
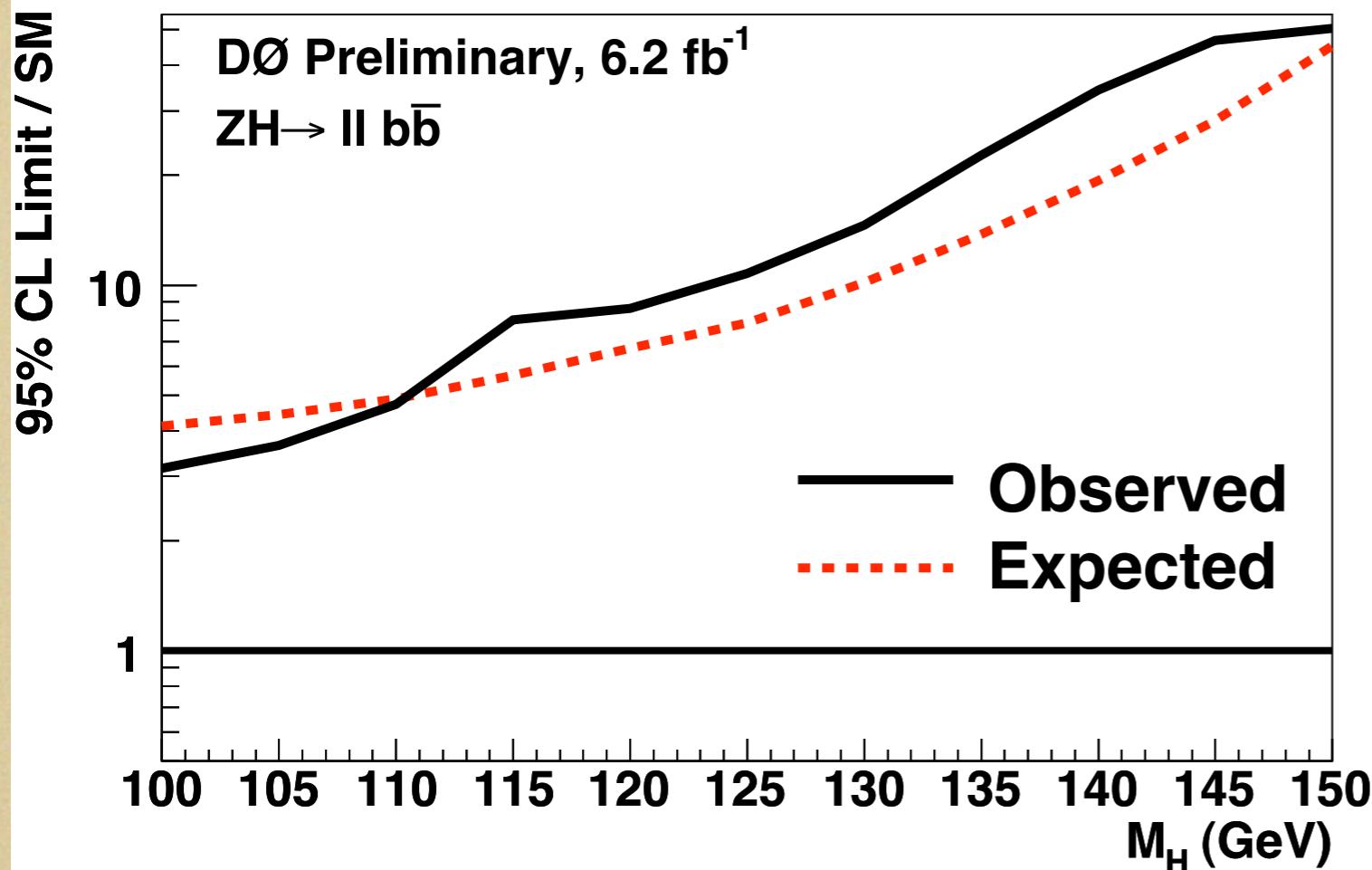


CDF uses a 2D NN:

- one axis is ZH vs Z+jets
- one axis is ZH vs ttbar
- Kinematic and Topological inputs
- A 10% slice along the ZH vs ttbar is for display (full 2D is used in limit)



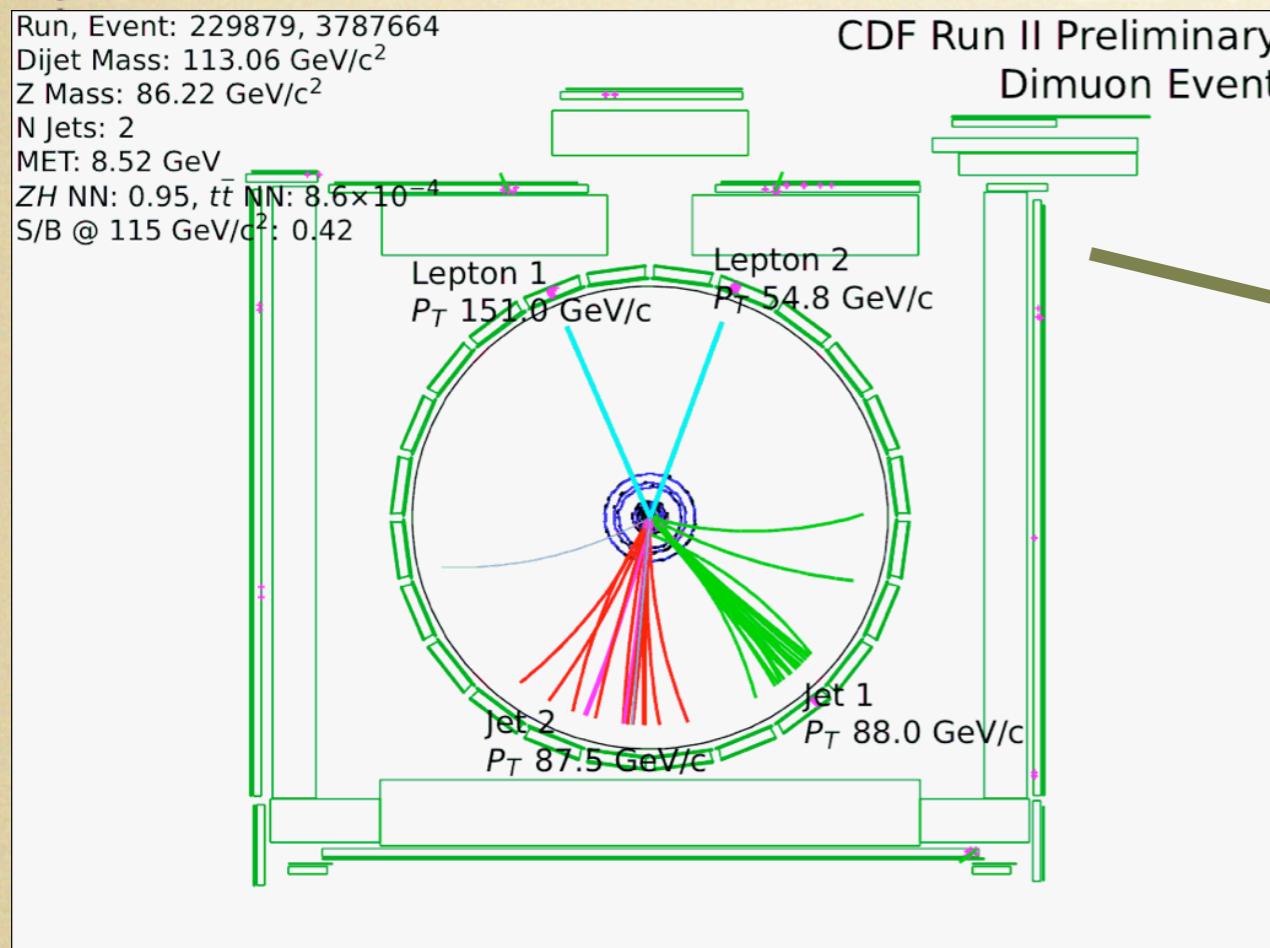
# $ZH \rightarrow \ell\ell b\bar{b}$ Limits



Subchannels  
combined.

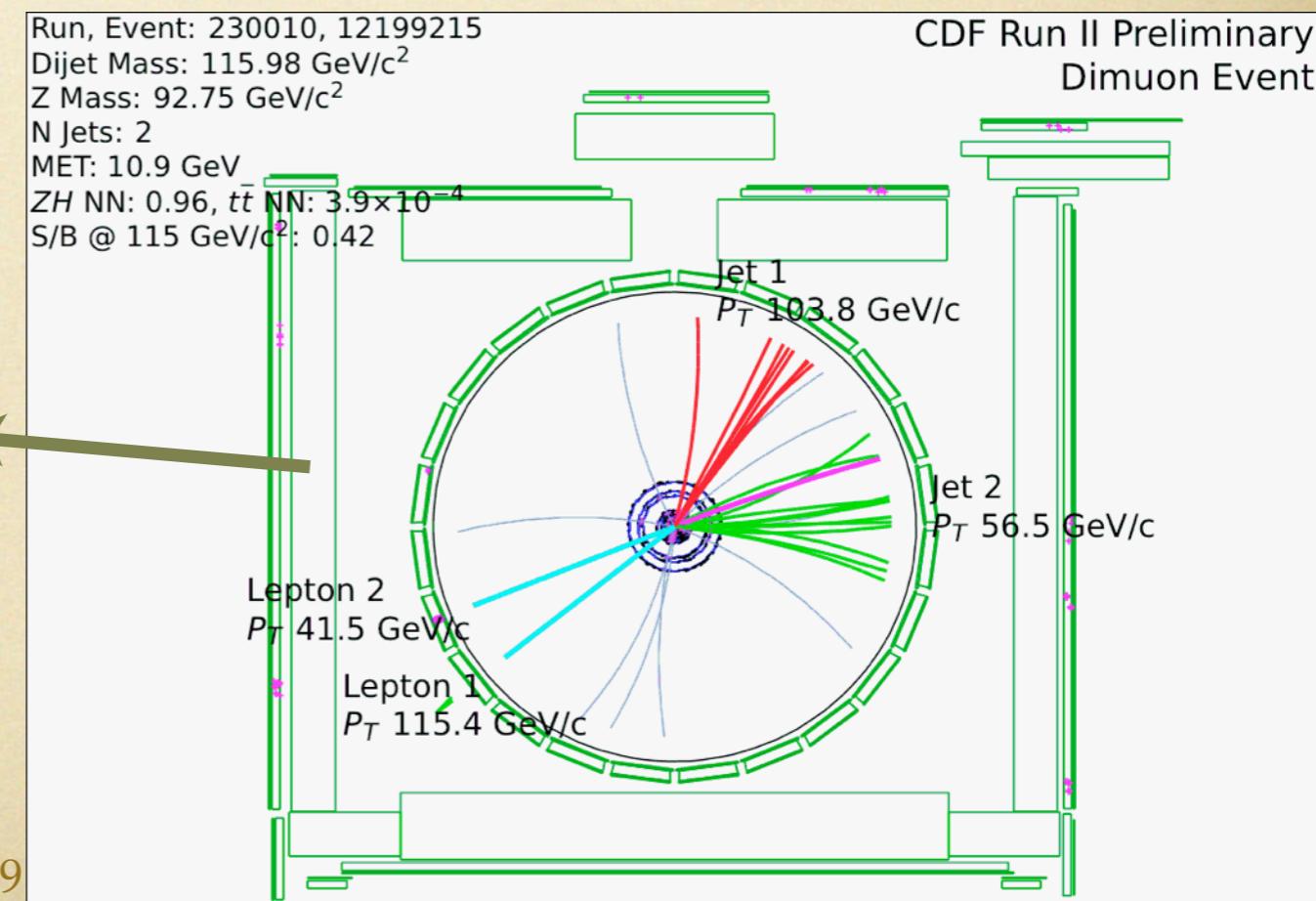
Experiment	Lum	Obs/SM	Exp/SM
D0	$6.2 \text{ fb}^{-1}$	8.0	5.7
CDF	$5.7 \text{ fb}^{-1}$	6.0	5.5

# Events



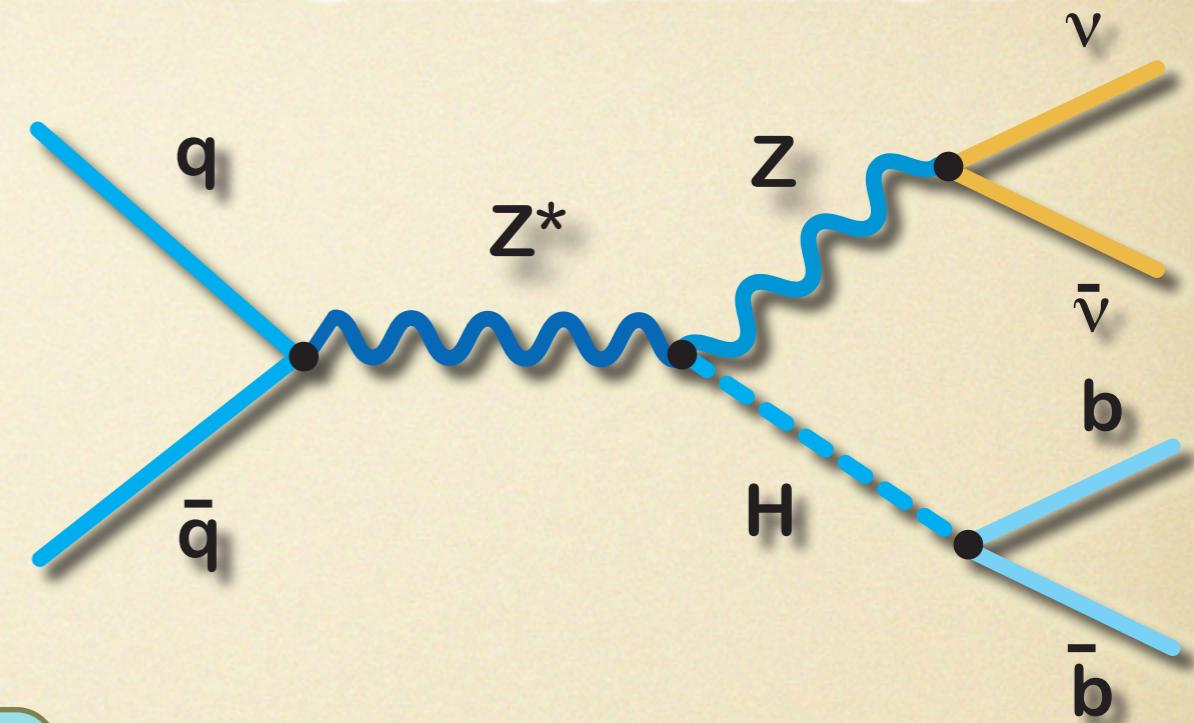
Dijet Mass = 113  $\text{GeV}/c^2$   
 Z Mass = 86.2  $\text{GeV}/c^2$   
 MET = 8.5 GeV  
 $NN_{ZH} = 0.95; NN_{tt} = \sim 10^{-3}$

Dijet Mass = 116  $\text{GeV}/c^2$   
 Z Mass = 92.8  $\text{GeV}/c^2$   
 MET = 10.9 GeV  
 $NN_{ZH} = 0.96; NN_{tt} = \sim 10^{-3}$



# $ZH \rightarrow \nu\nu b\bar{b}$ Channel

- No High  $P_T$  charged lep.
- Large Missing  $E_T$
- 2 jets
- Require 2 b-tags



## Features:

1. Trigger is more challenging
2. Large QCD/Fake Bkgs
  - i. Difficult to Simulate
  - ii. Use data to est. bkgns
3. **Use tracks to help bkg identification.**
4.  $\sim 2-3$  evts/ $fb^{-1}$

## Primary Backgrounds

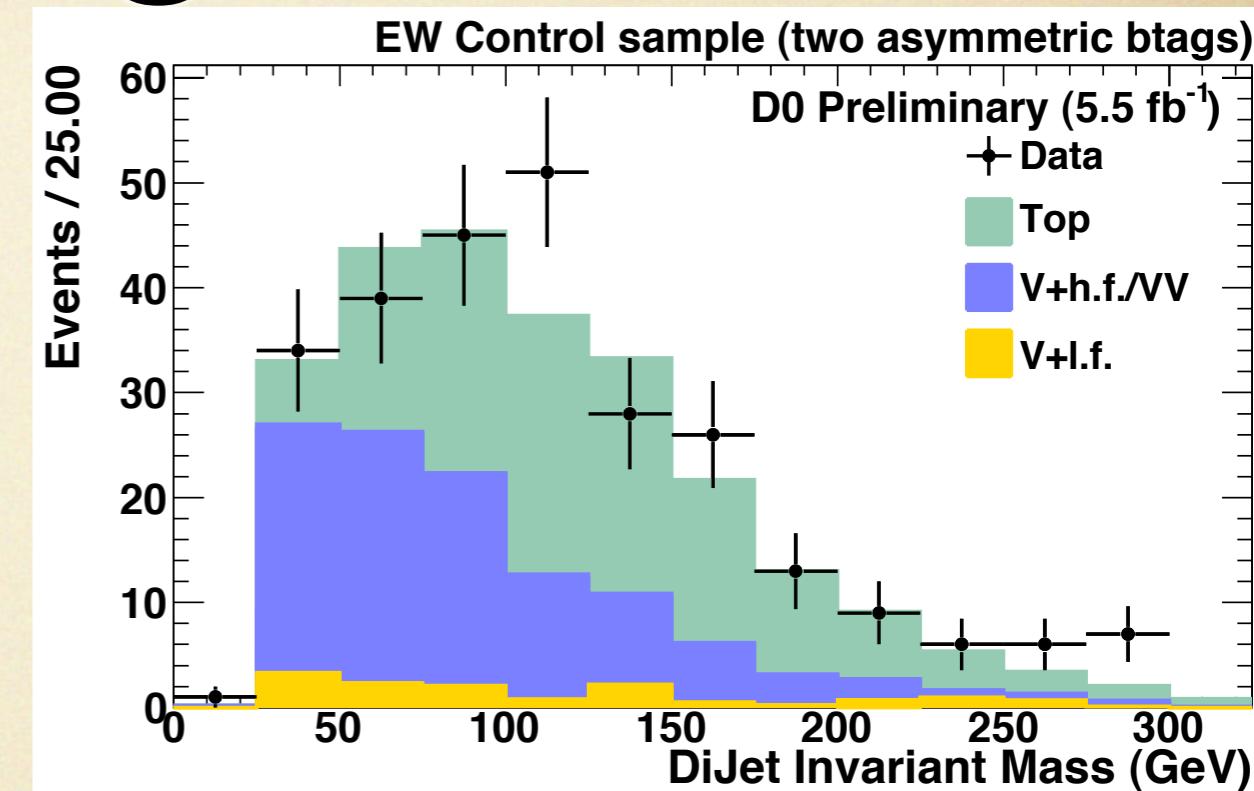
QCD Heavy Flavor,  
 $t\bar{t}$ ,  $W/Z + b\bar{b}/c\bar{c}$ ,  
 Single Top,  
 $ZZ$ ,  $WZ$ ,  $WW$

# $ZH \rightarrow \nu\nu b\bar{b}$ Background Model



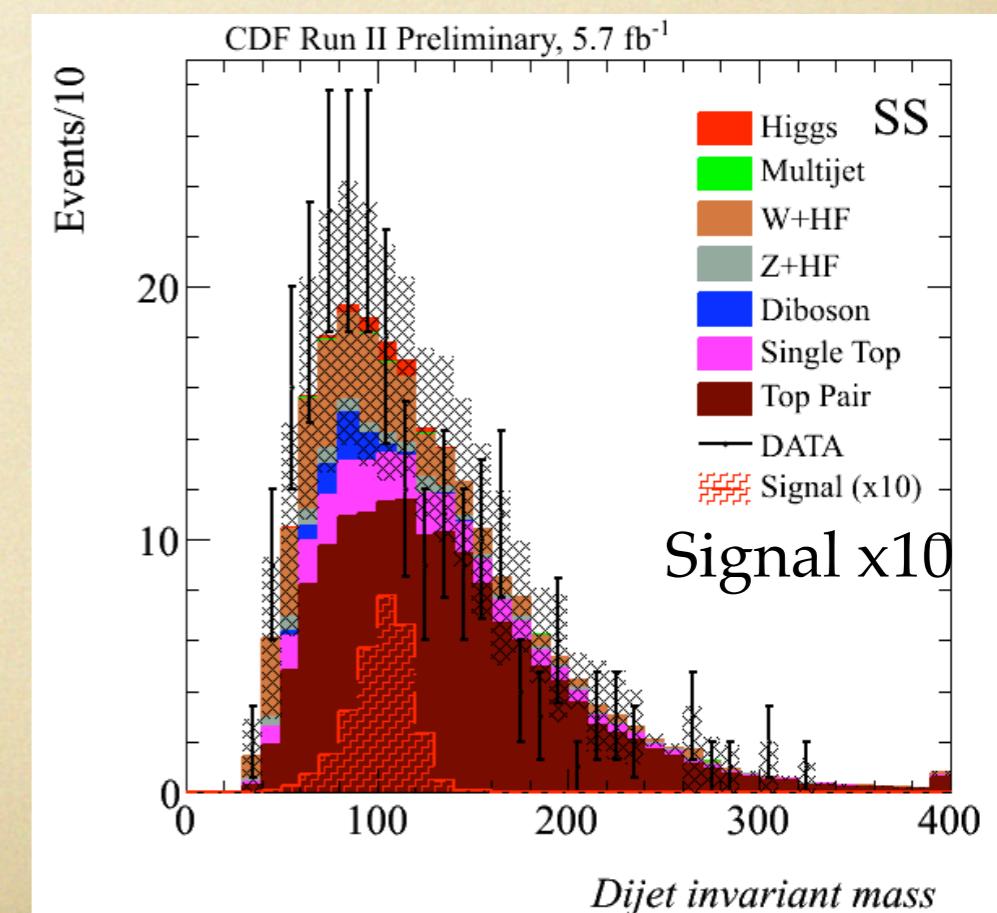
D0 divides data into 4 subsamples:

- Signal used to search for Higgs
- MJ-model for modeling MJ background in signal sample
- MJ-control to validate MJ-modelling
- EWK control, enhanced in  $W \rightarrow \mu\nu$



CDF divides data into 5 subsamples:

- Signal used to search for Higgs
- QCD Region for systematic studies
- EWK region for modeling ewk processes
- QCD Regions (2) to check normalization of MJ

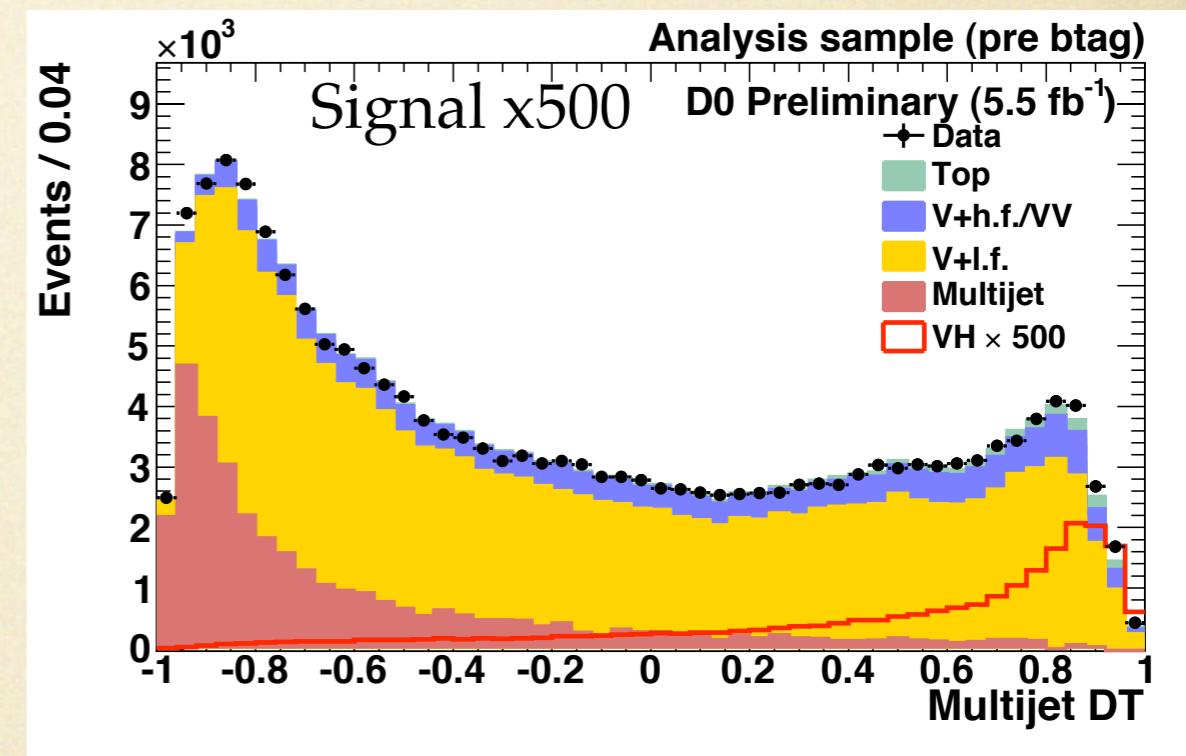


$ZH \rightarrow \nu\nu b\bar{b}$

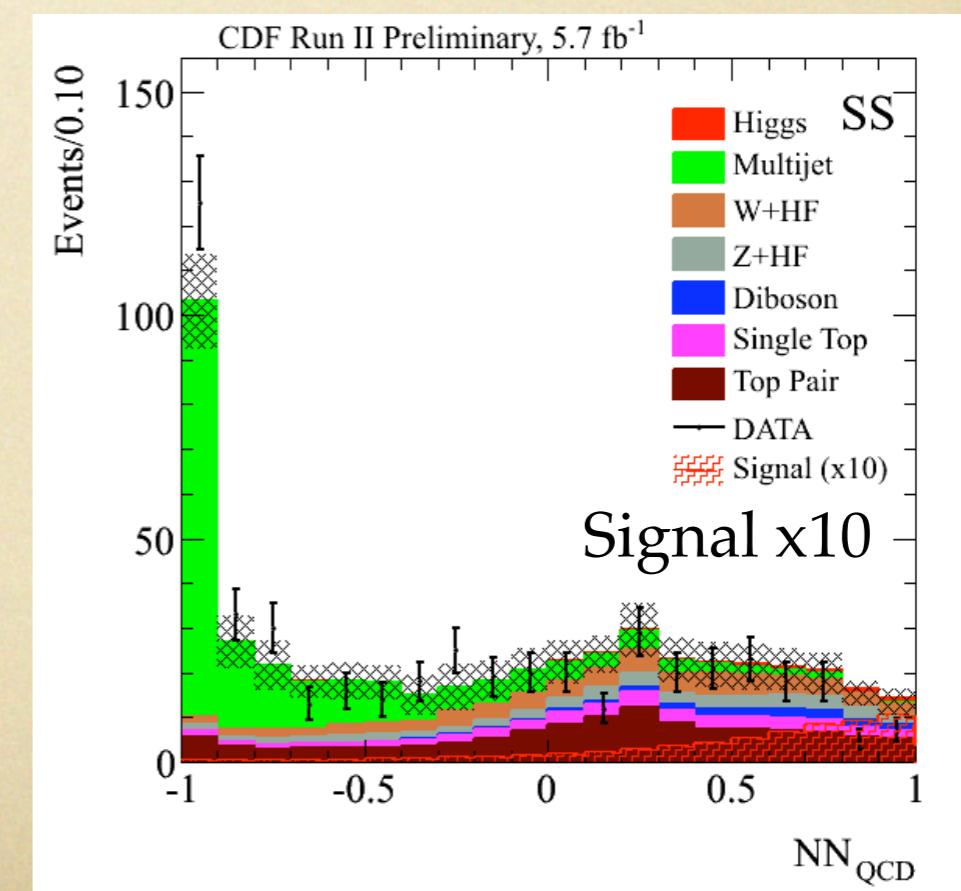


- D0 employs a Multijet Discriminant:
- Based on jet kinematics (but after a cut on “track-based missing transverse momentum”)
  - Removes 95% of MJ and 65% of non-MJ background
  - Preserves 70% of signal

# QCD Removal

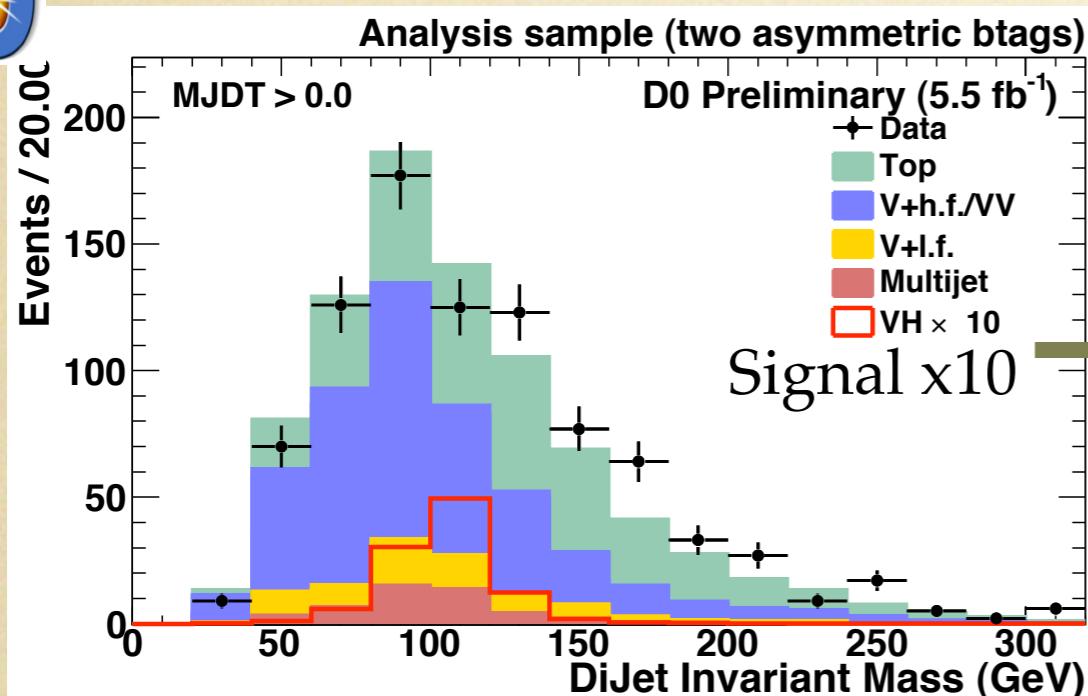


- CDF uses a QCD NN:
- Based on Jet kinematics as well as “track missing transverse momentum”
  - Removes 87% of MJ, 50-70% of non-MJ background
  - Preserves 90-95% of signal

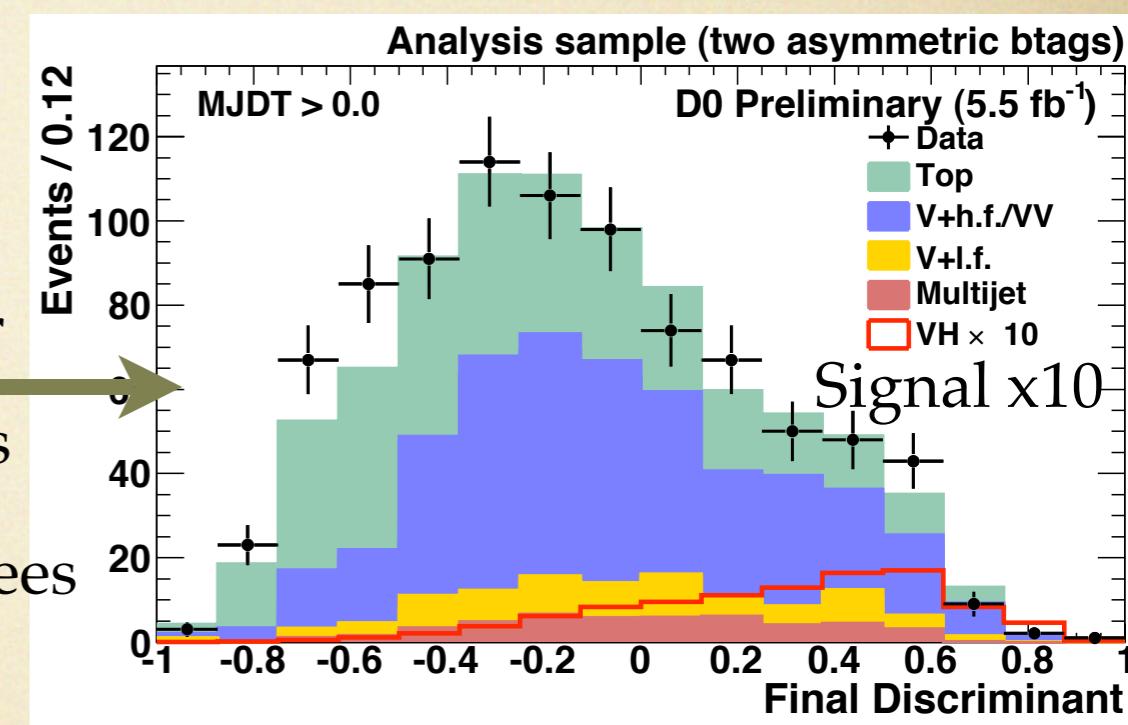


$ZH \rightarrow \nu\nu b\bar{b}$

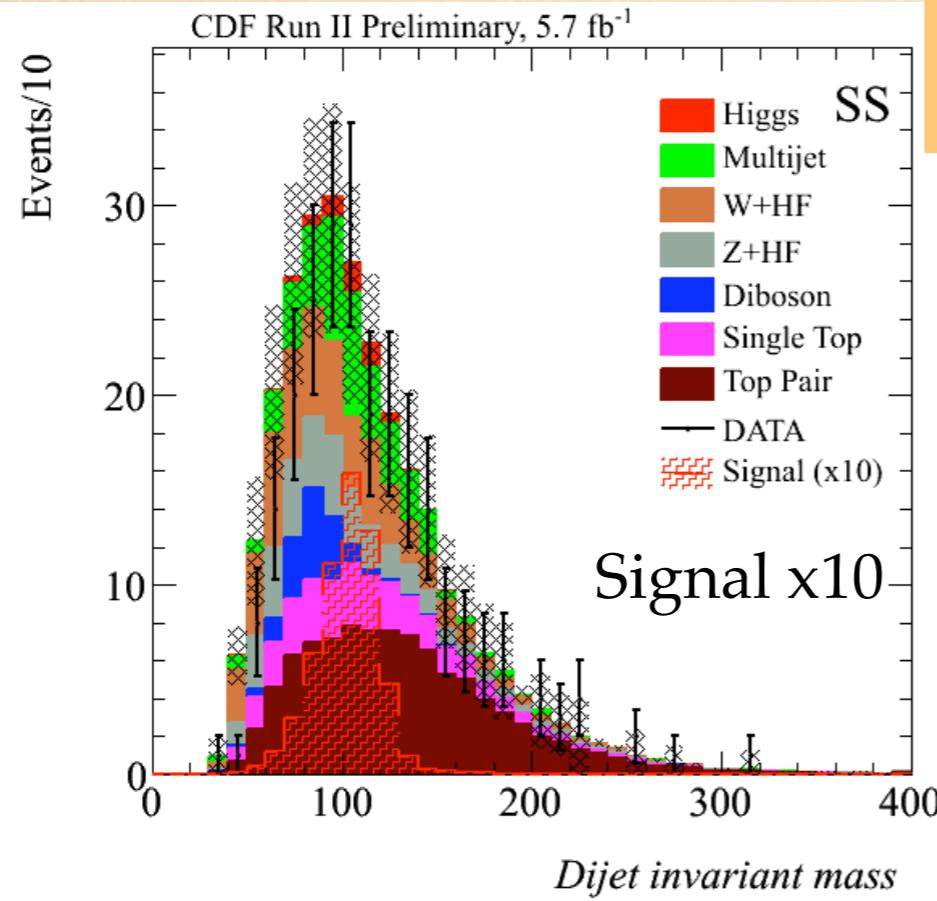
# Event Discriminants



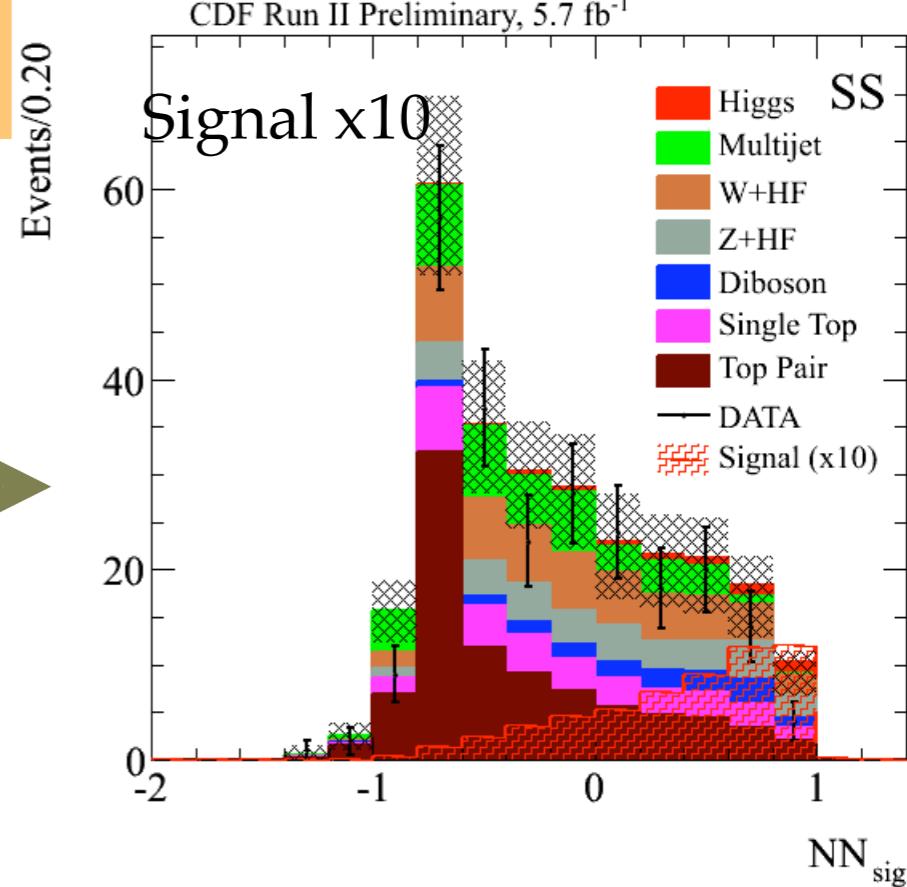
+19 other quantities  
Decision Trees



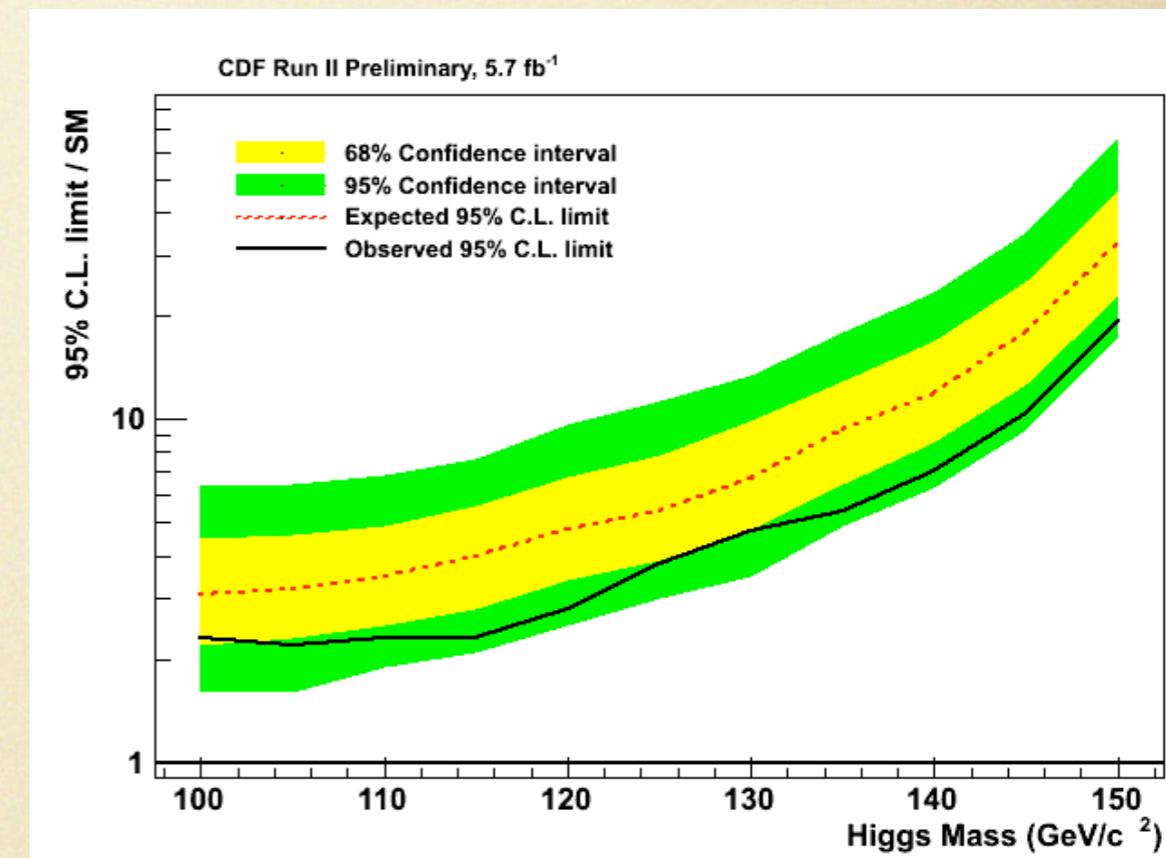
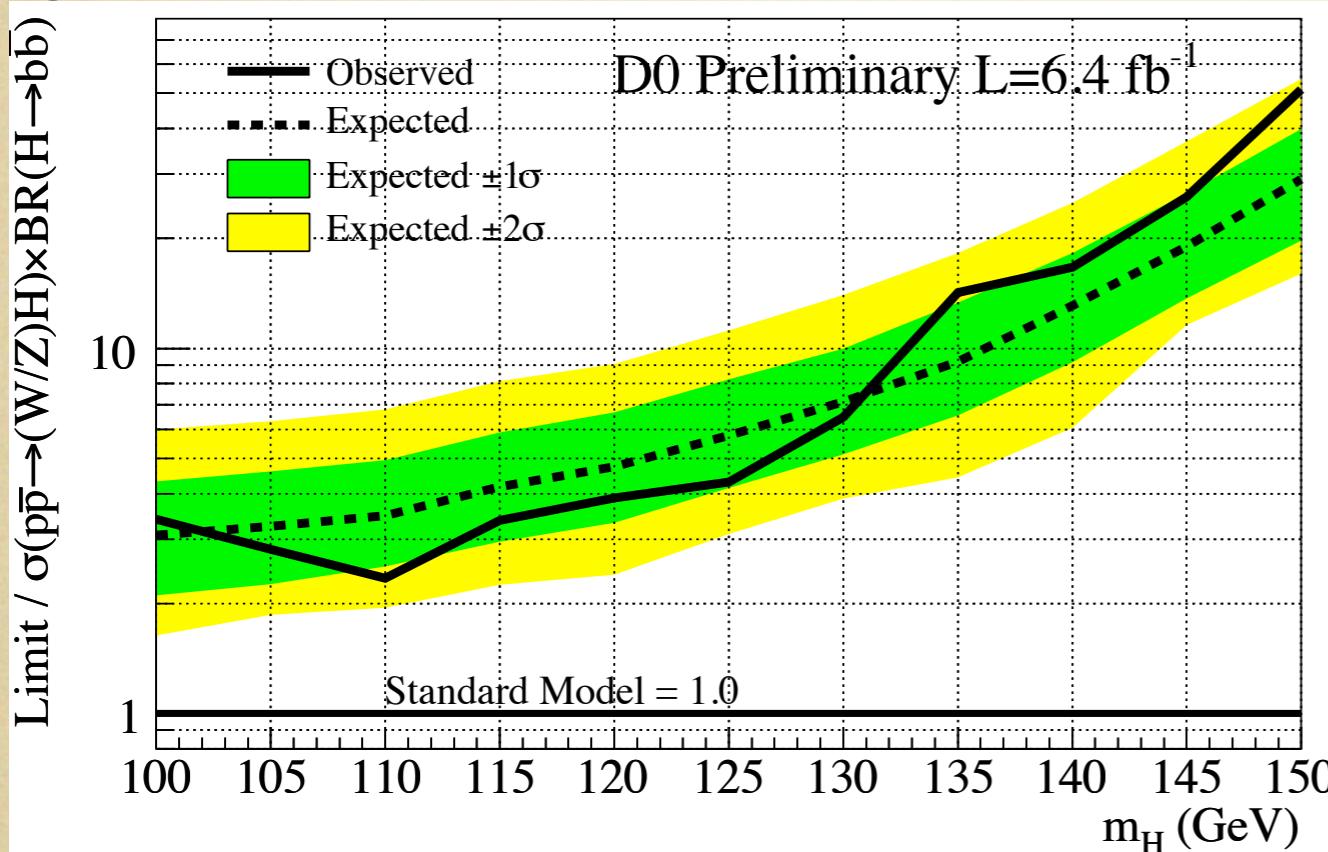
Best subchannels;  
others contribute  
as well



+5 other  
quantities  
Neural Network



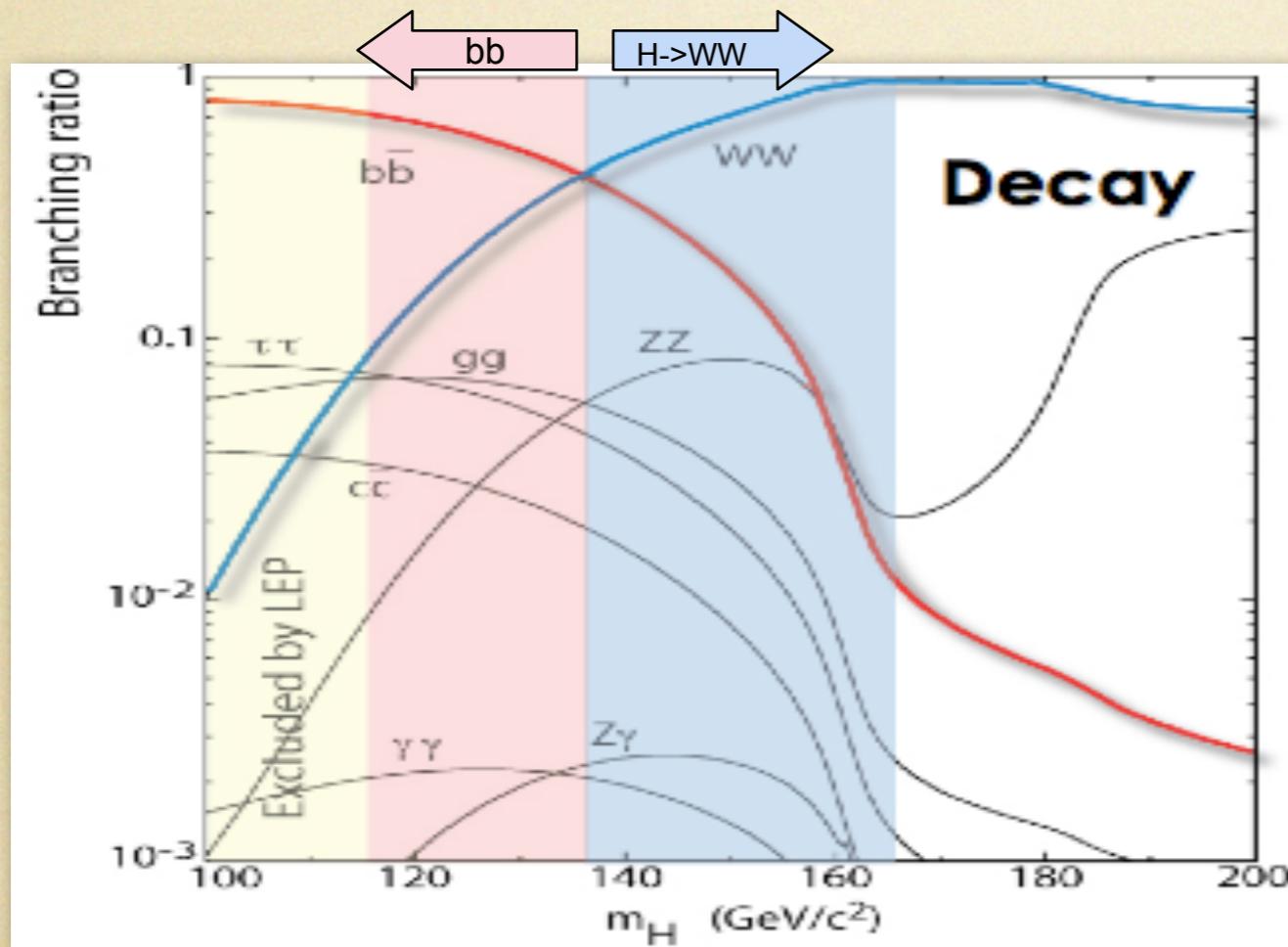
# $ZH \rightarrow \nu\nu b\bar{b}$ Limits



Subchannels  
combined.

Experiment	Lum	Obs/SM	Exp/SM
D0	$6.4 \text{ fb}^{-1}$	3.4	4.2
CDF	$5.7 \text{ fb}^{-1}$	2.3	4.0

# High Mass Signature



Remember:  
Primarily H → WW

# High Mass WW Final States

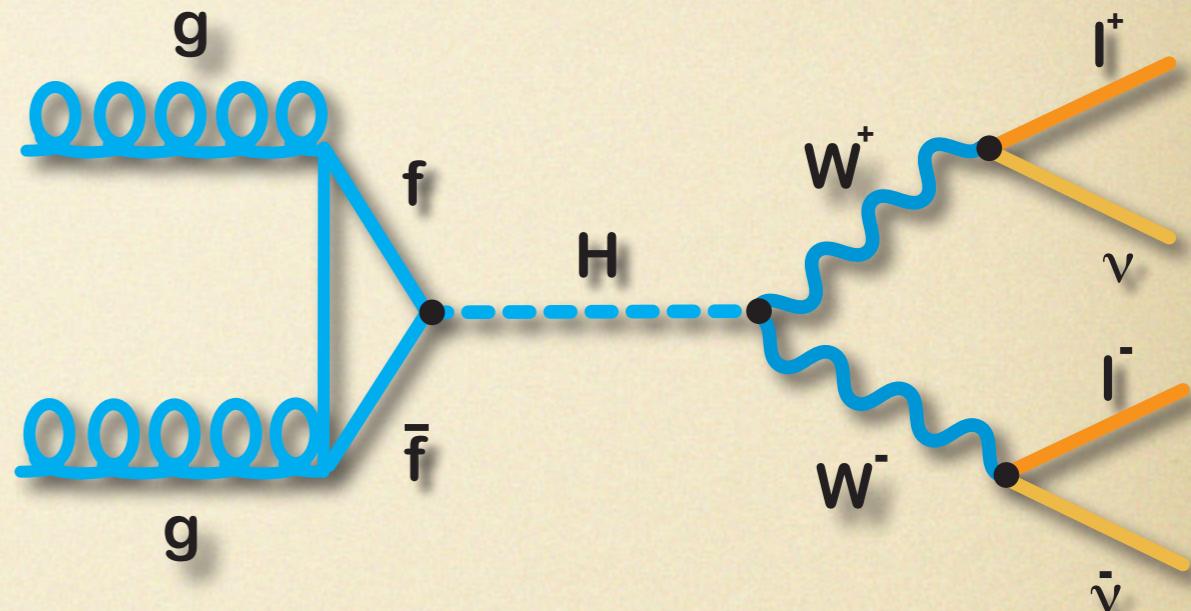
W Decay	electron + jets	muon + jets	tau + jets	all hadronic
$\tau e$	$\tau \mu$	$\tau \tau$		tau + jets
$e\mu$	$\mu\mu$	$\tau\mu$		muon + jets
$ee$	$e\mu$	$\tau e$		electron + jets

W Decay

The diagram shows a 4x5 grid of final state categories. The columns are labeled "W Decay" at the bottom and the rows are labeled "W Decay" on the left. The first three columns represent W decays to leptons and jets, while the last two represent all-hadronic decays. The first row contains the labels for these categories. The second row lists the specific decay channels:  $\tau e$ ,  $\tau \mu$ ,  $\tau \tau$ , tau + jets;  $e\mu$ ,  $\mu\mu$ ,  $\tau\mu$ , muon + jets; and  $ee$ ,  $e\mu$ ,  $\tau e$ , electron + jets. A red circle highlights the  $e\mu$  entry in the third column of the second row.

$\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$  Channel

- Two High  $P_T$  e or  $\mu$ 
  - \* Opposite Charge
- Large Missing  $E_T$



Features:

1. Most signif. for high mass
2. No kinematic mass peak
3. Higher production x-sec.
4. No b-tag eff. reduction.
5. Spin 0 Higgs  $\rightarrow$  Ang. Corr.
6.  $\sim 2-4$  evts /  $fb^{-1}$

Primary Backgrounds

$WW, WZ, ZZ,$   
 $W + \text{jets}, t\bar{t},$   
 $Z^{(*)} \rightarrow \ell\ell$

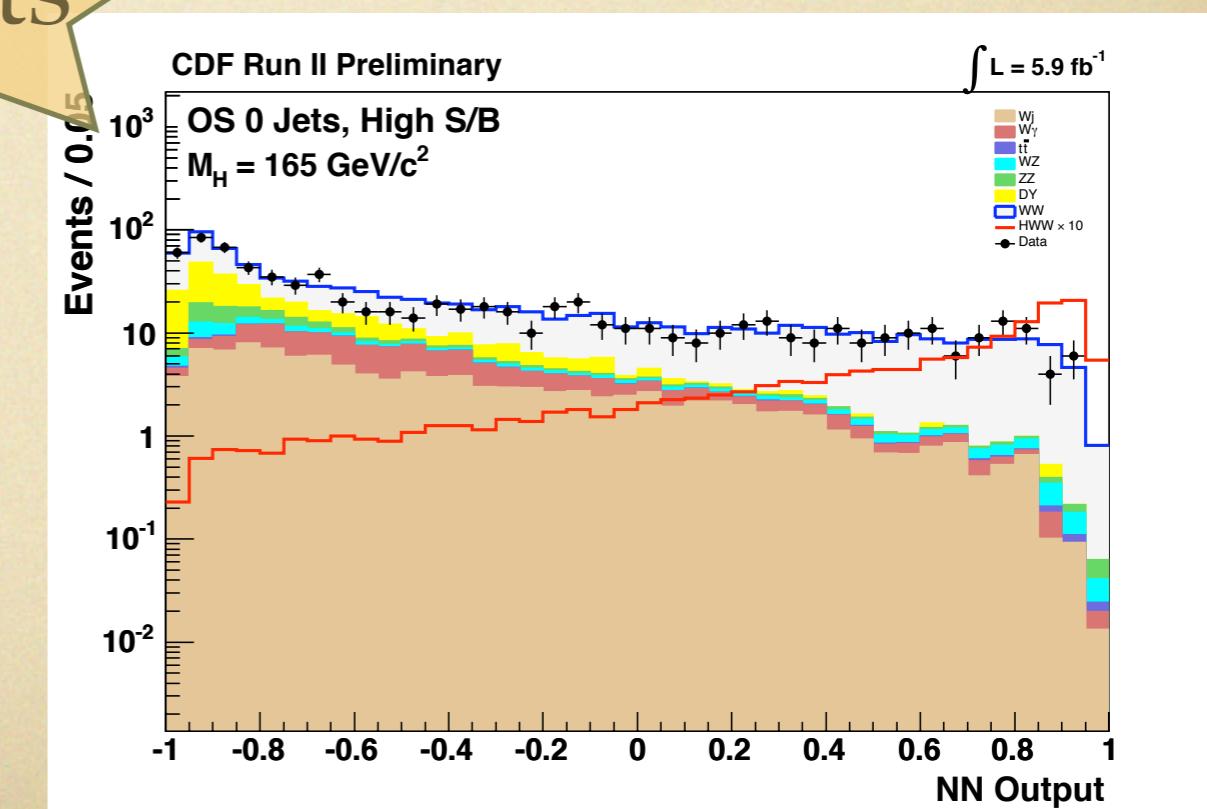
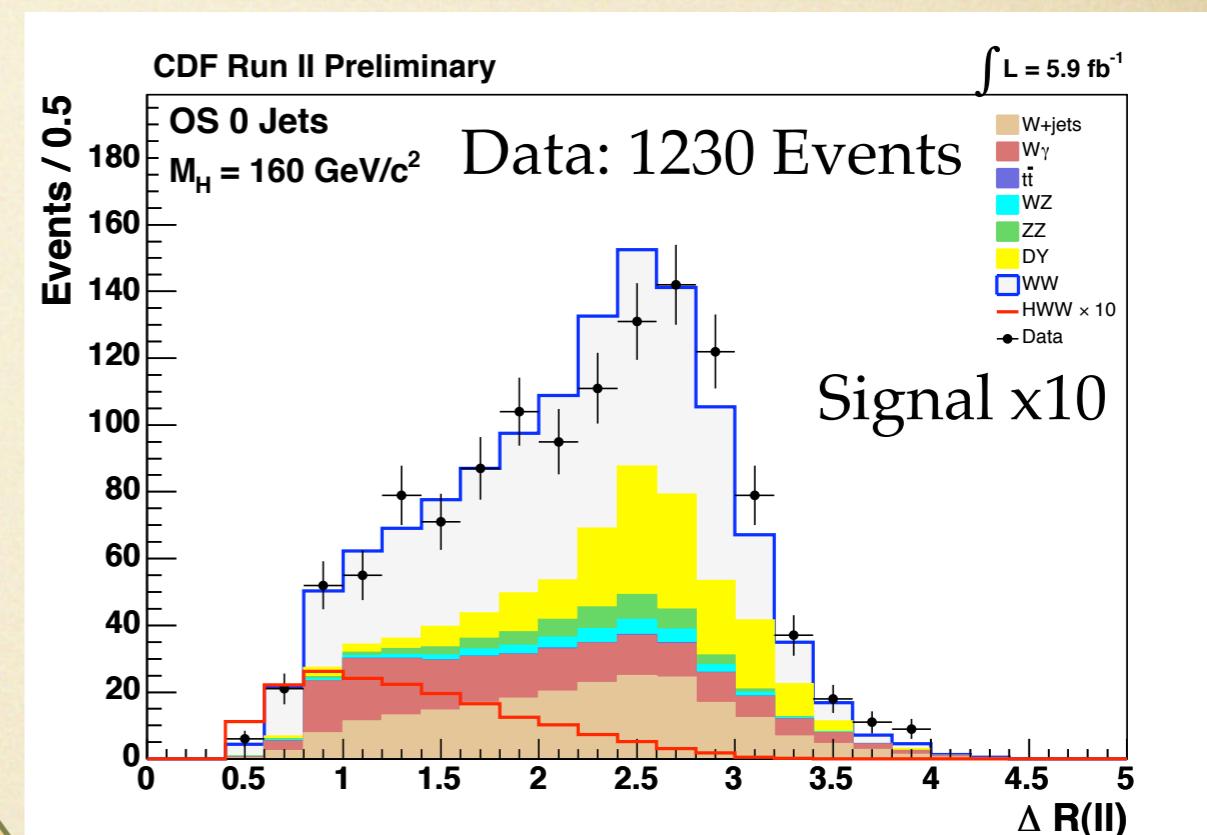
# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel



- High  $P_T$  e or  $\mu$  and  $E_T$
- Separate Samples
  - \* High and Low S/B
  - \* Number of Jets
- Discriminant
  - \* Topological/Kin Quantities
  - \* Matrix Element (LR)
  - \* Optimized for each sub-channels

Sample	Events
Background	$1226 \pm 26$
$gg \rightarrow H$	$16.9 \pm 3.0$
WH	$0.41 \pm 0.07$
ZH	$0.42 \pm 0.06$
VBF	$0.14 \pm 0.03$

0 jets



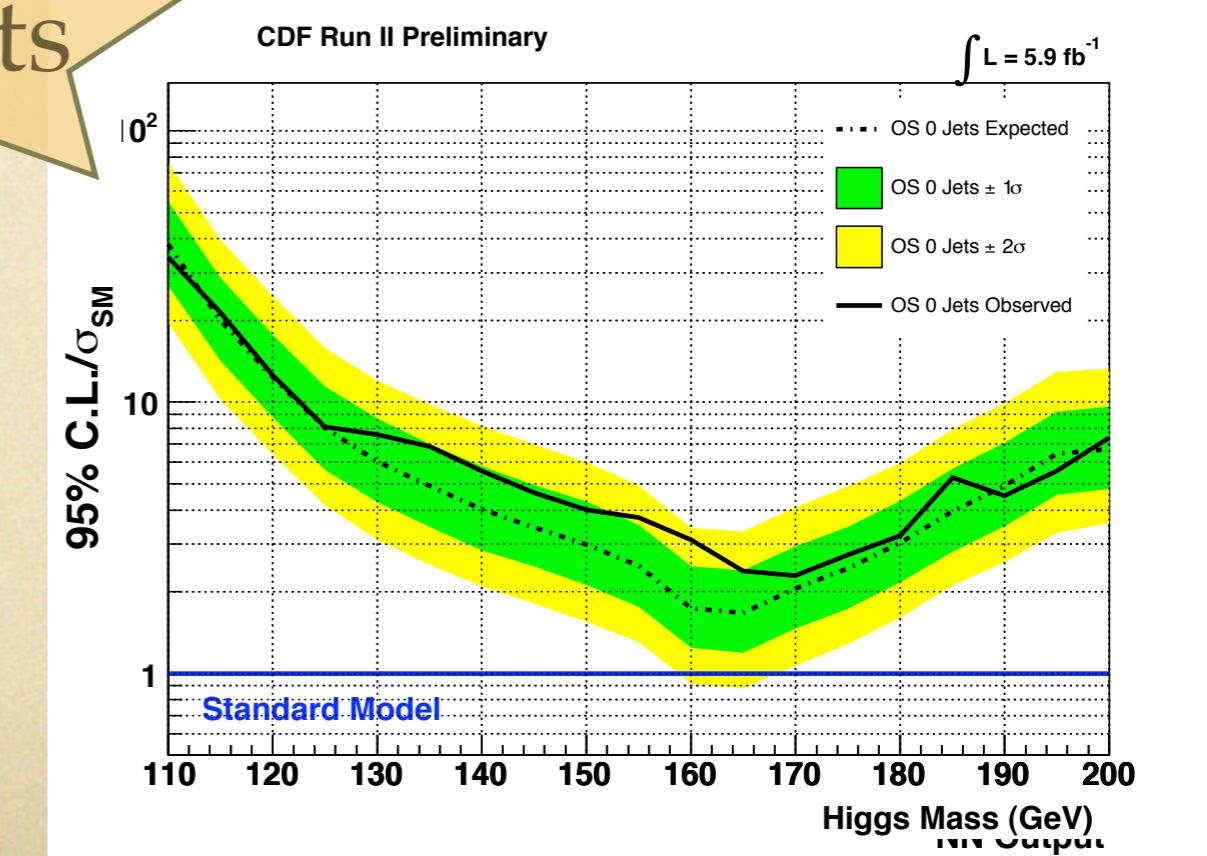
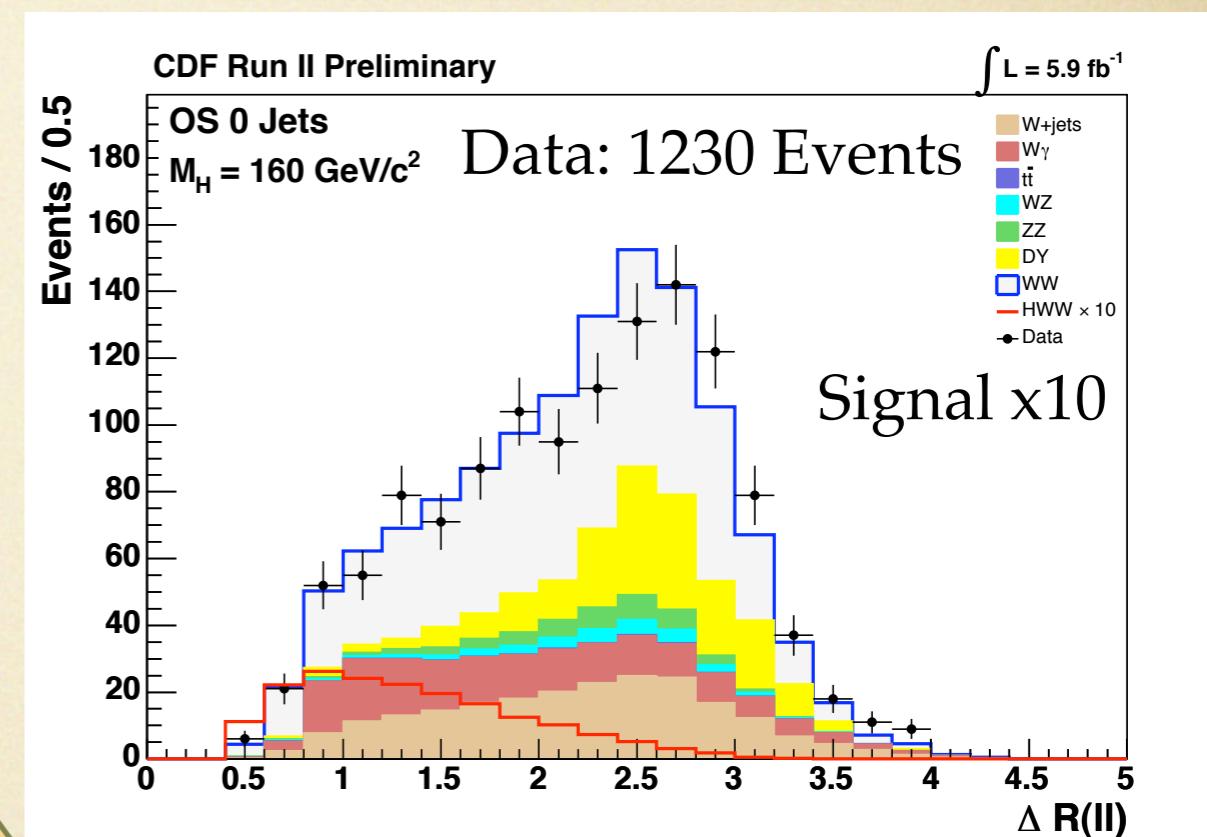
# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel



- High  $P_T$  e or  $\mu$  and  $E_T$
- Separate Samples
  - \* High and Low S/B
  - \* Number of Jets
- Discriminant
  - \* Topological/Kin Quantities
  - \* Matrix Element (LR)
  - \* Optimized for each sub-channels

Sample	Events
Background	$1226 \pm 26$
$gg \rightarrow H$	$16.9 \pm 3.0$
$WH$	$0.41 \pm 0.07$
$ZH$	$0.42 \pm 0.06$
VBF	$0.14 \pm 0.03$

0 jets

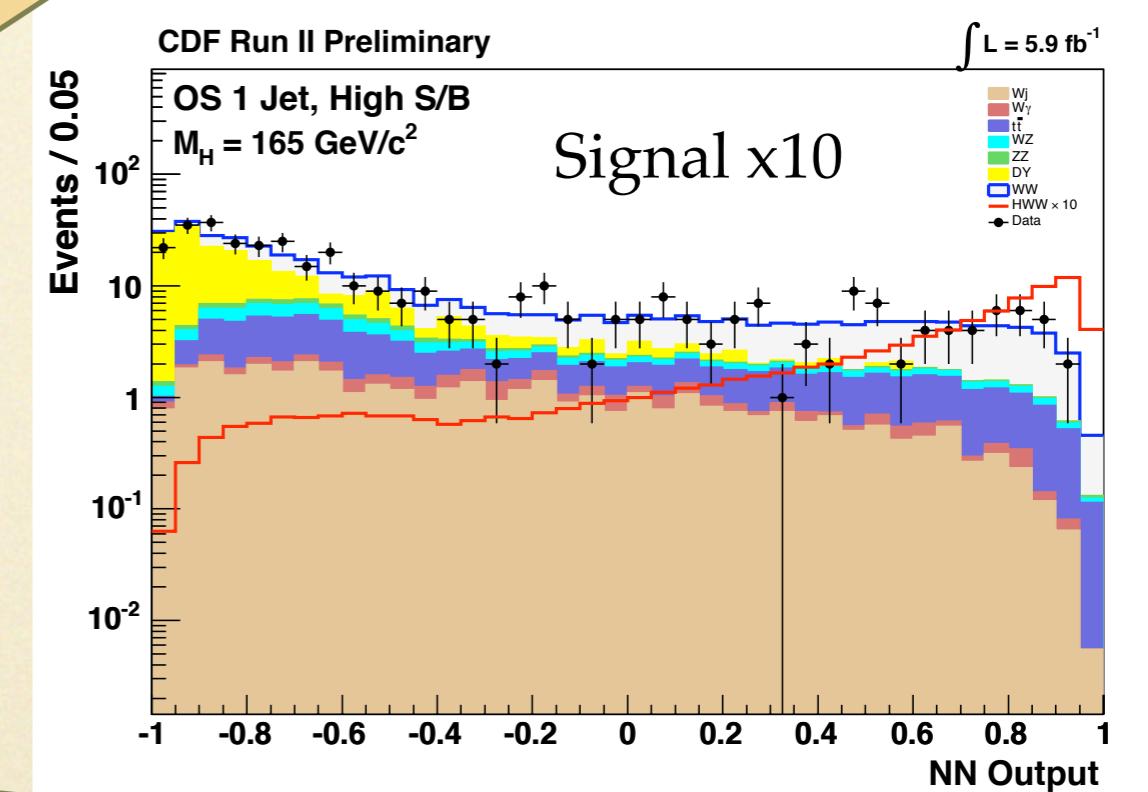




# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel

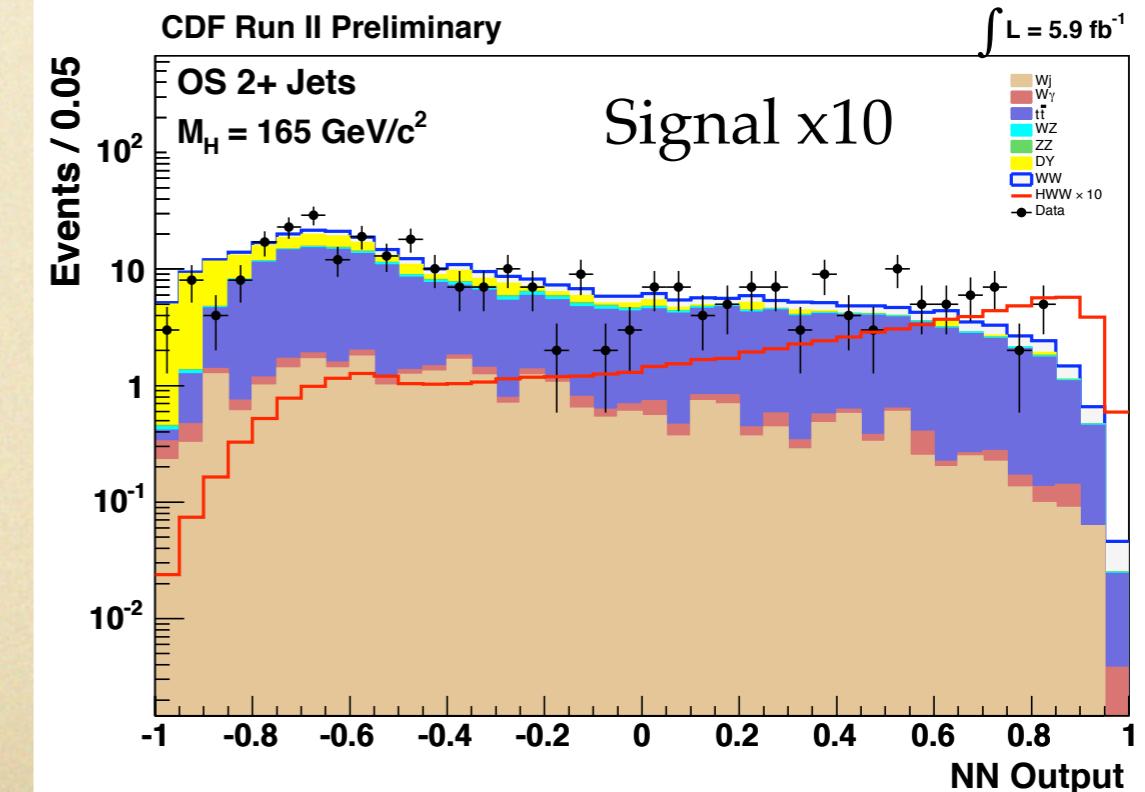
Data: 533 Events

Sample	Events
Background	$563 \pm 69$
gg $\rightarrow H$	$8.0 \pm 2.4$
WH	$1.13 \pm 0.18$
ZH	$0.44 \pm 0.07$
VBF	$0.74 \pm 0.13$



Data: 307 Events

Sample	Events
Background	$324 \pm 50$
gg $\rightarrow H$	$2.6 \pm 1.8$
WH	$2.5 \pm 0.35$
ZH	$1.28 \pm 0.17$
VBF	$1.37 \pm 0.23$





# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel

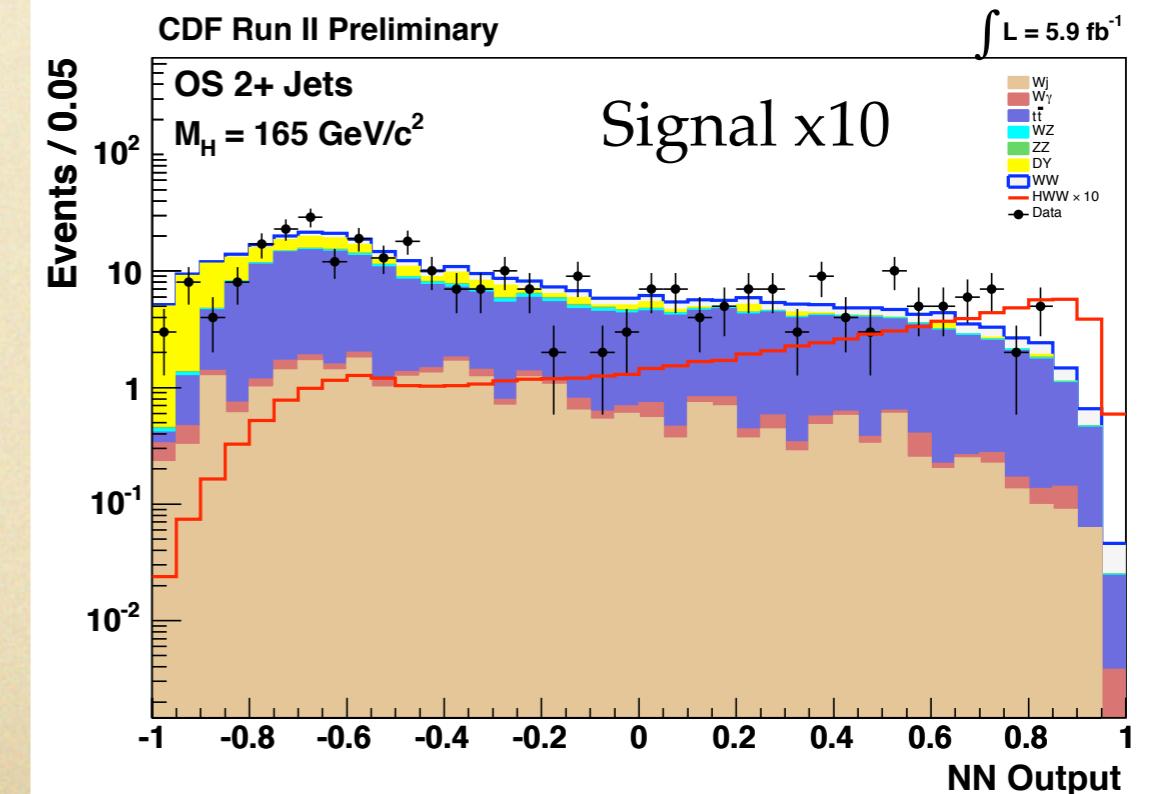
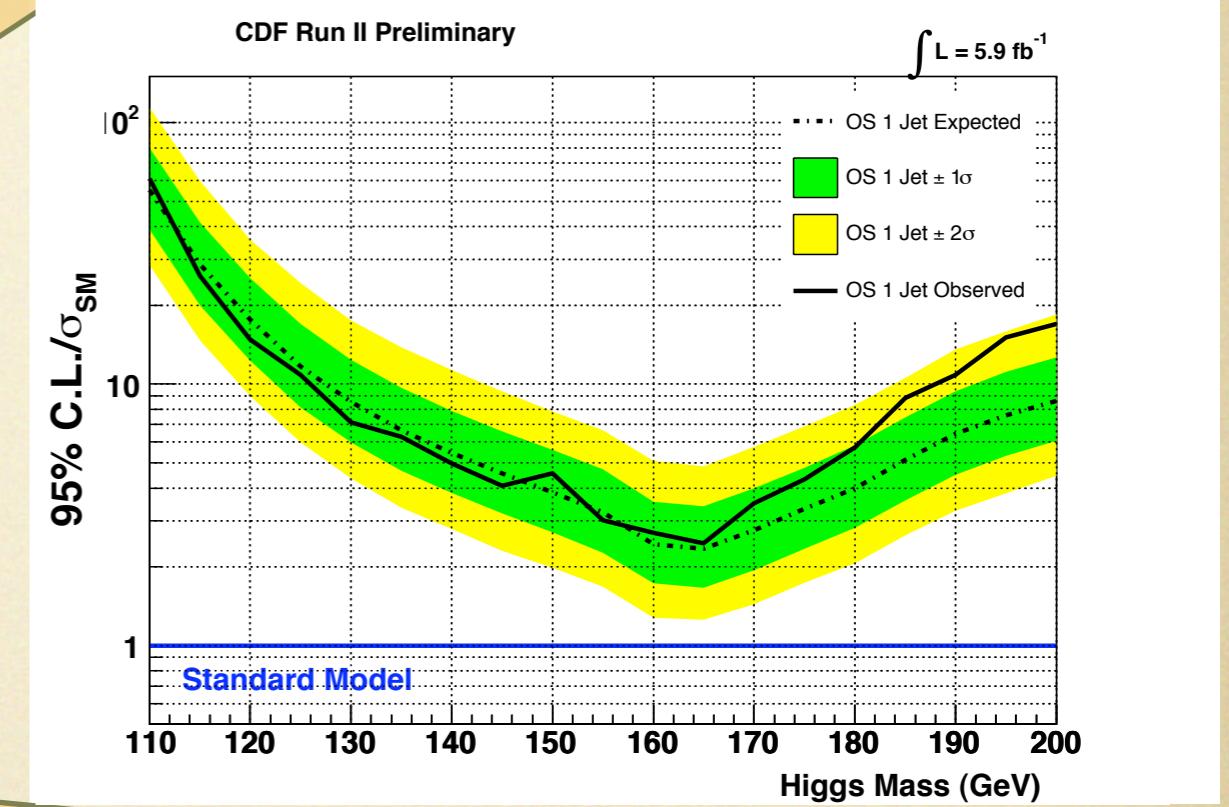
Data: 533 Events

Sample	Events
Background	$563 \pm 69$
gg $\rightarrow H$	$8.0 \pm 2.4$
WH	$1.13 \pm 0.18$
ZH	$0.44 \pm 0.07$
VBF	$0.74 \pm 0.13$



Data: 307 Events

Sample	Events
Background	$324 \pm 50$
gg $\rightarrow H$	$2.6 \pm 1.8$
WH	$2.5 \pm 0.35$
ZH	$1.28 \pm 0.17$
VBF	$1.37 \pm 0.23$





# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel

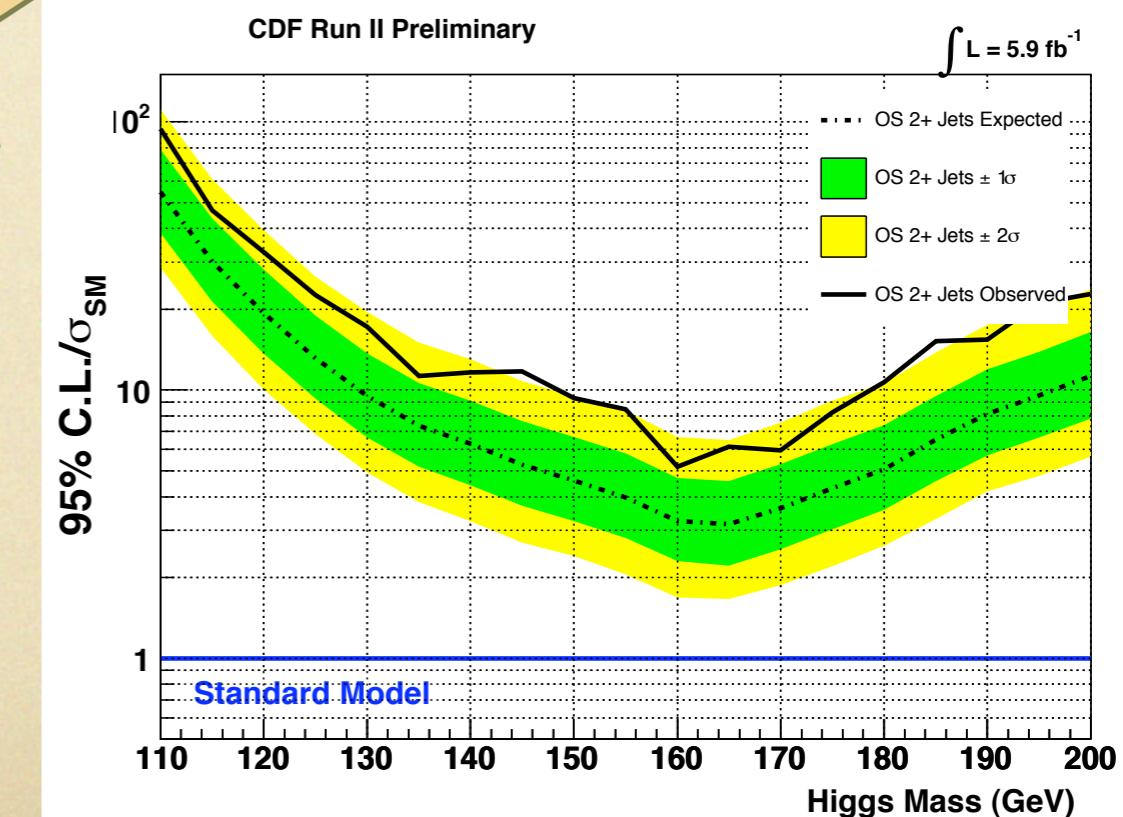
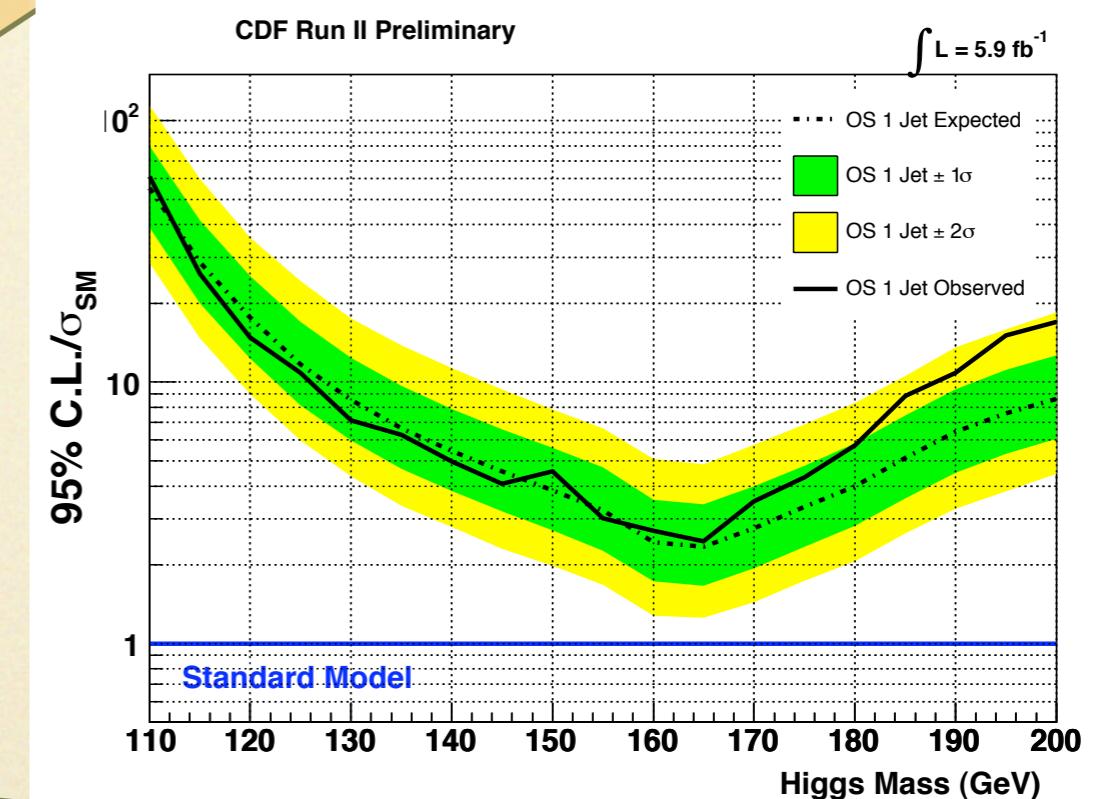
Data: 533 Events

Sample	Events
Background	$563 \pm 69$
gg $\rightarrow H$	$8.0 \pm 2.4$
WH	$1.13 \pm 0.18$
ZH	$0.44 \pm 0.07$
VBF	$0.74 \pm 0.13$



Data: 307 Events

Sample	Events
Background	$324 \pm 50$
gg $\rightarrow H$	$2.6 \pm 1.8$
WH	$2.5 \pm 0.35$
ZH	$1.28 \pm 0.17$
VBF	$1.37 \pm 0.23$



# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel



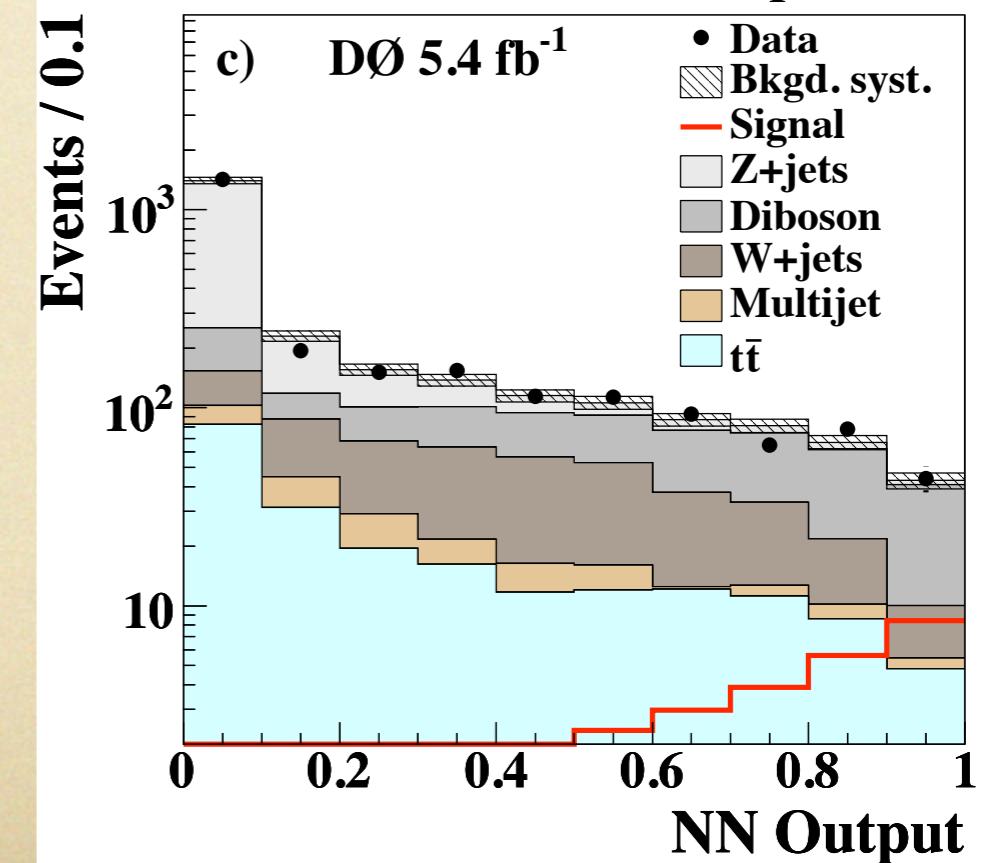
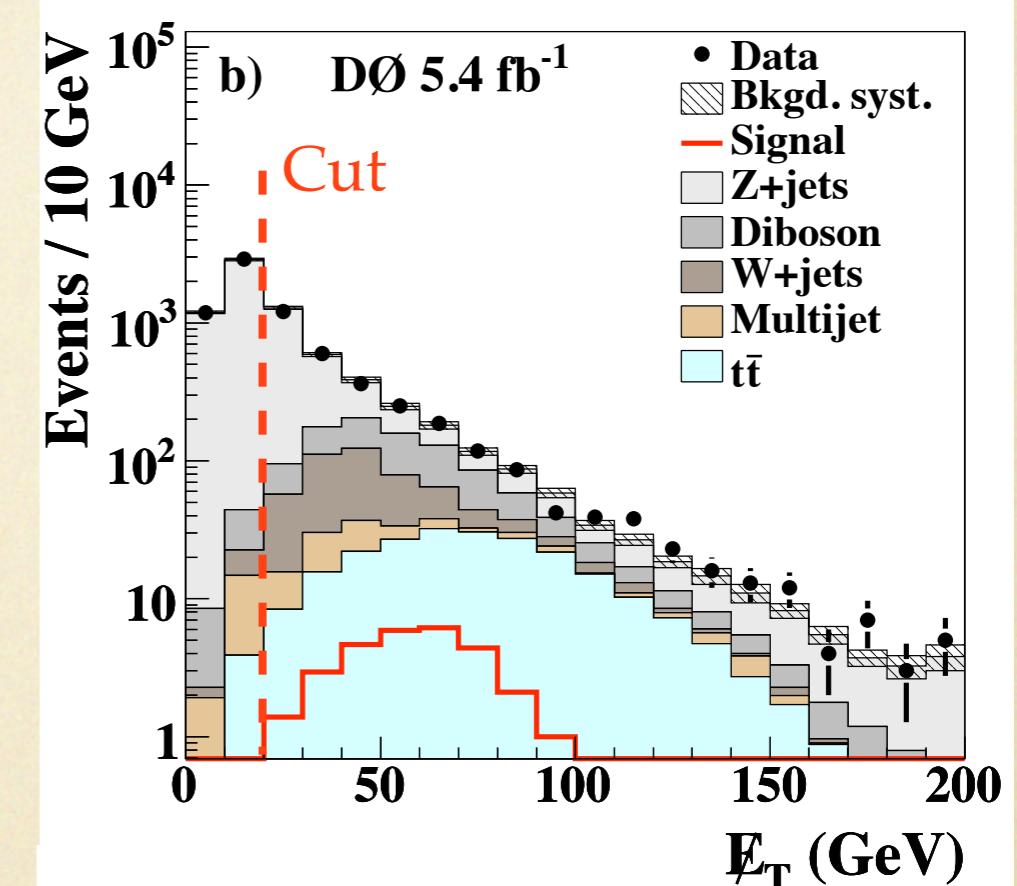
[Phys. Rev. Lett. 104, 061804 \(2010\)](#)

- High  $P_T$  e or  $\mu$  and  $E_T$
- Separate Samples
  - \* ee,  $\mu\mu$ ,  $e\mu$
- Discriminant
  - \* Topological/Kinematic Quantities
  - \* Number of Jets

Sample	Events
e $\mu$ Data	399
e $\mu$ Bkg	$397 \pm 14$
e $\mu$ Signal	$13.5 \pm 1.5$
ee Data	421
ee Bkg	$423 \pm 19$
ee Signal	$7.2 \pm 0.8$
$\mu\mu$ Data	$1613 \pm$
$\mu\mu$ Bkg	$1625 \pm 41$
$\mu\mu$ Signal	$9.0 \pm 1.0$

} Best S/B

40

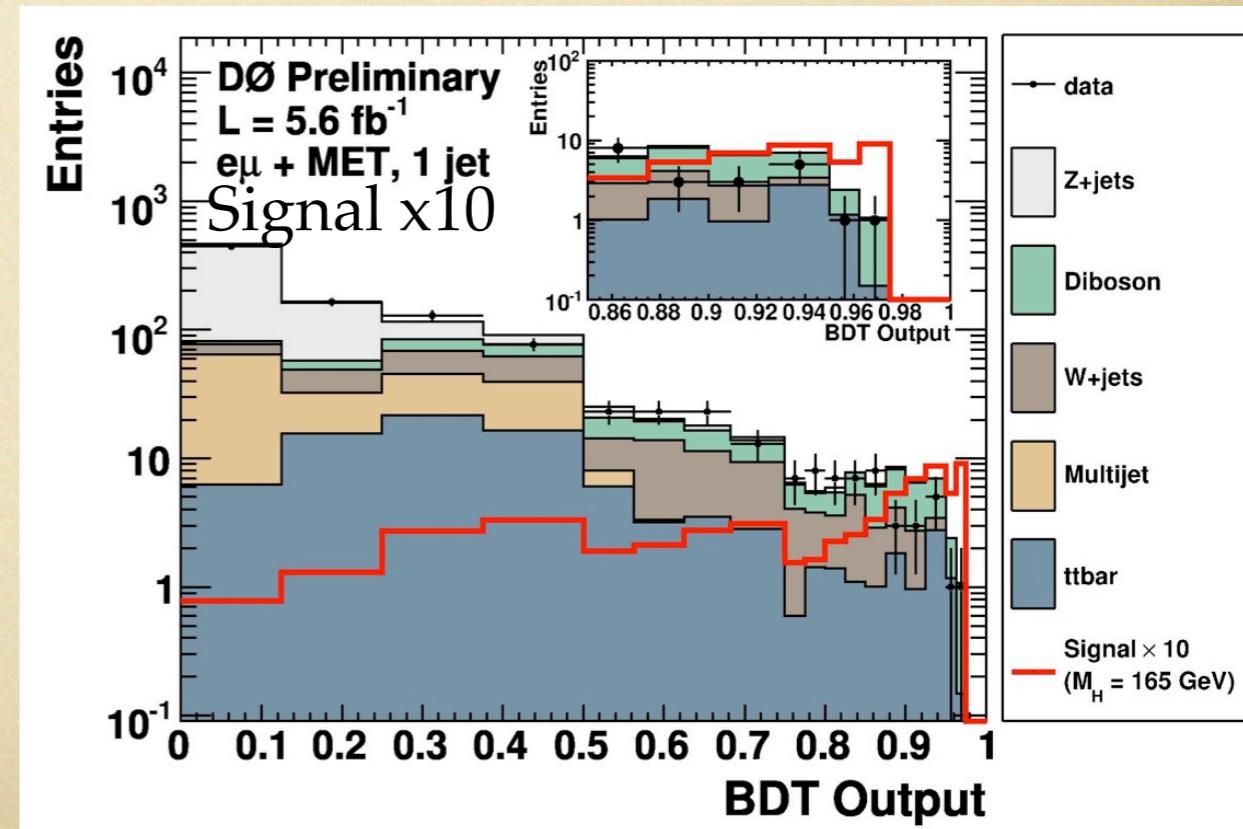
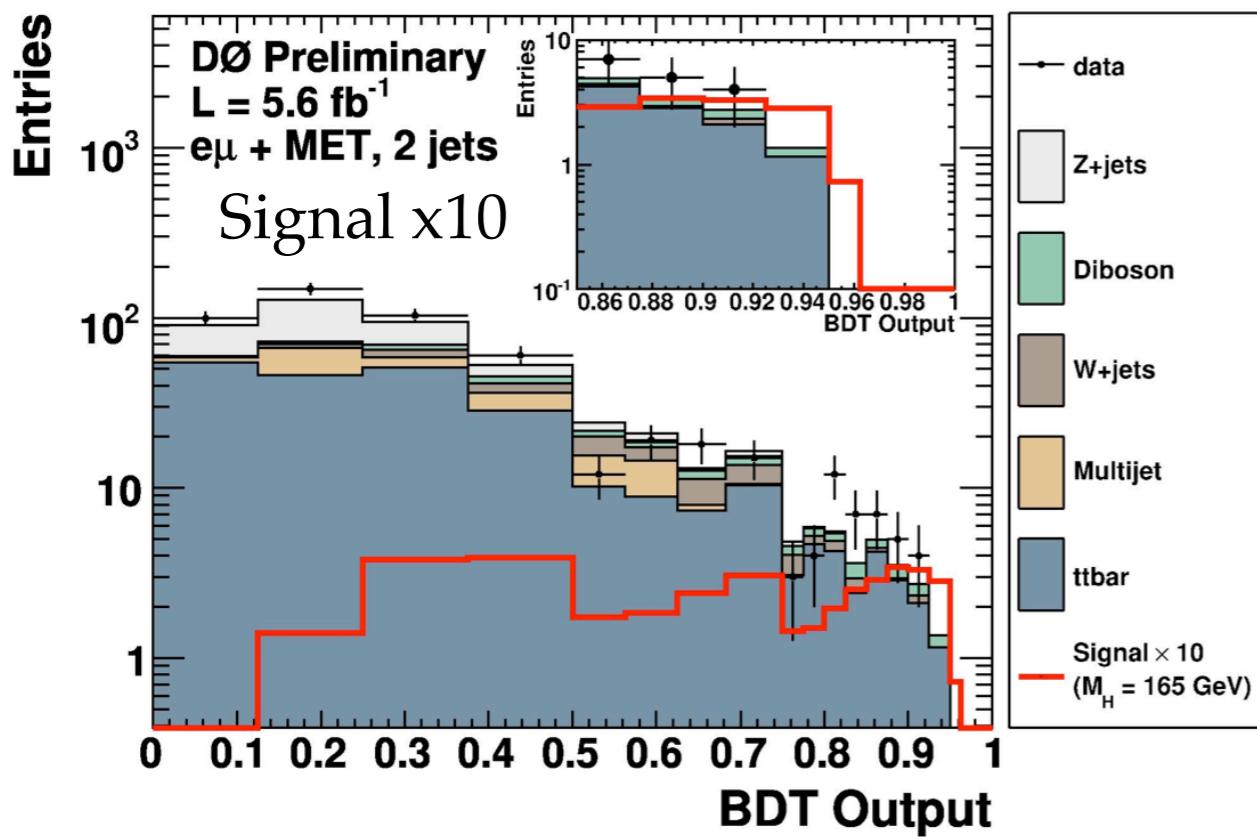
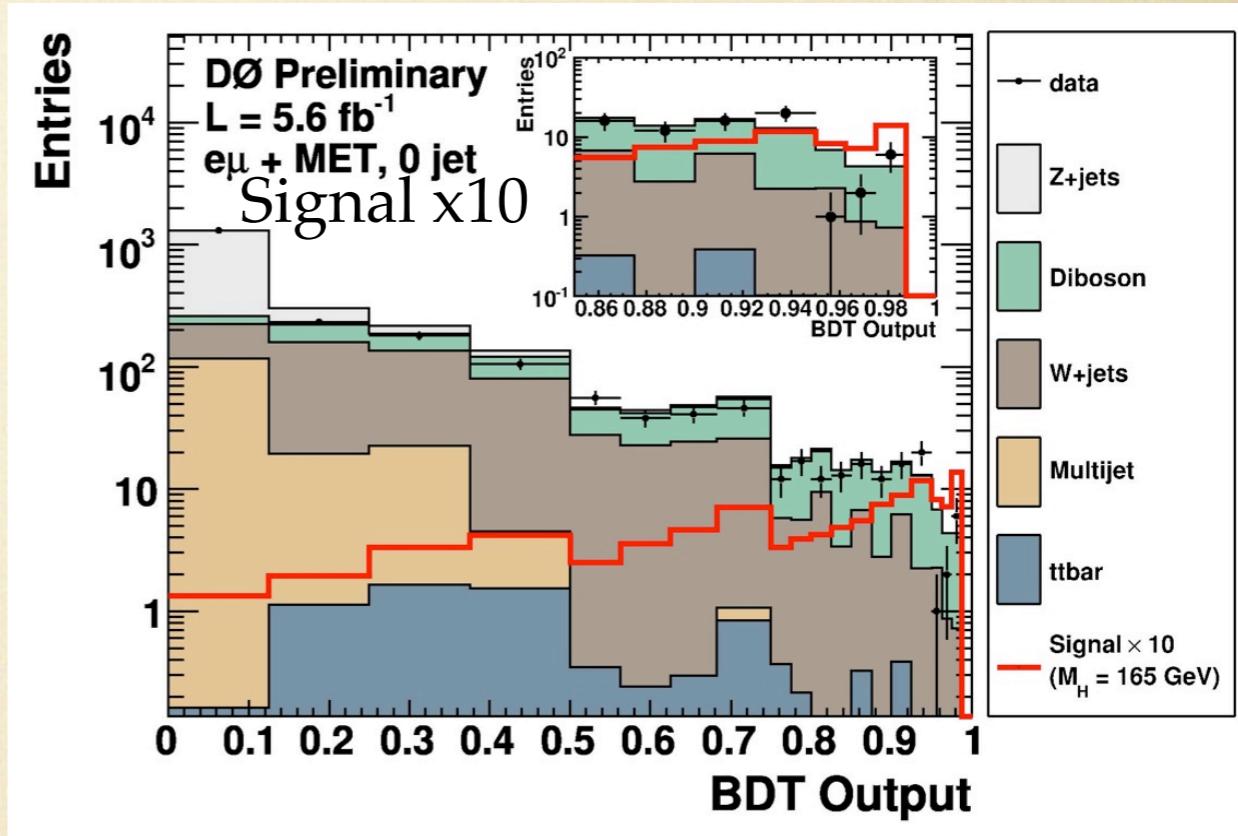


# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel



- Extended  $e\mu$  analysis
  - \* Separate by N-jets
  - \* Use Boosted Decision Tree
  - \* Use more data ( $+1.2 \text{ fb}^{-1}$ )

- Combined with  $ee, \mu\mu$

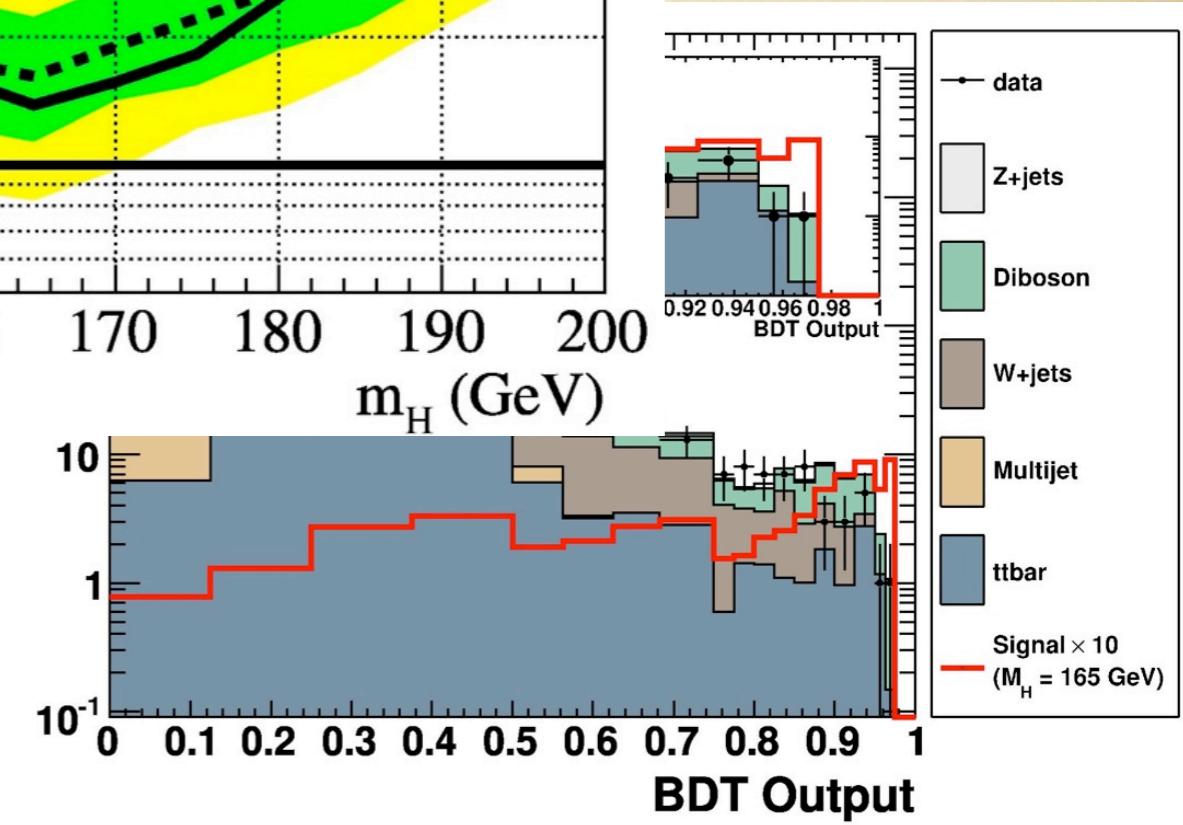
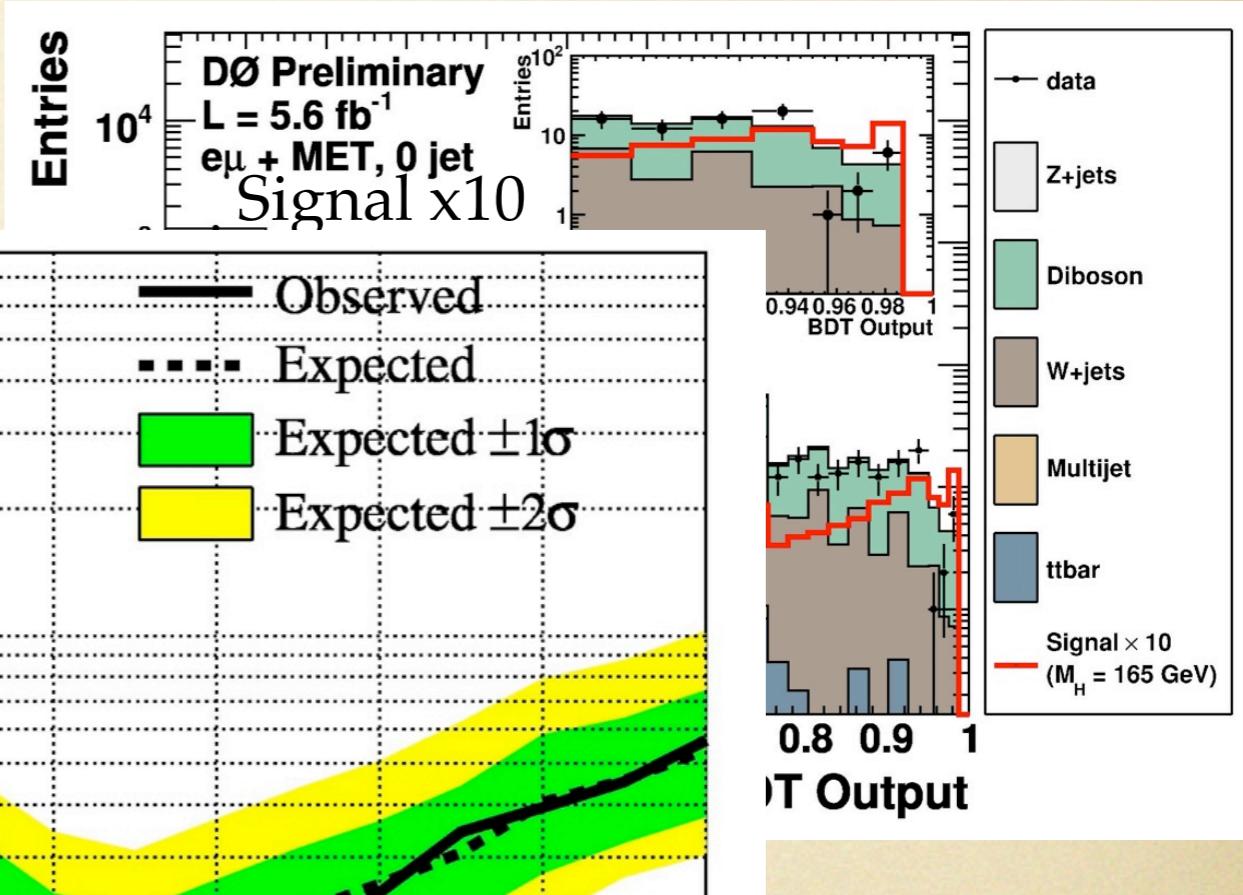
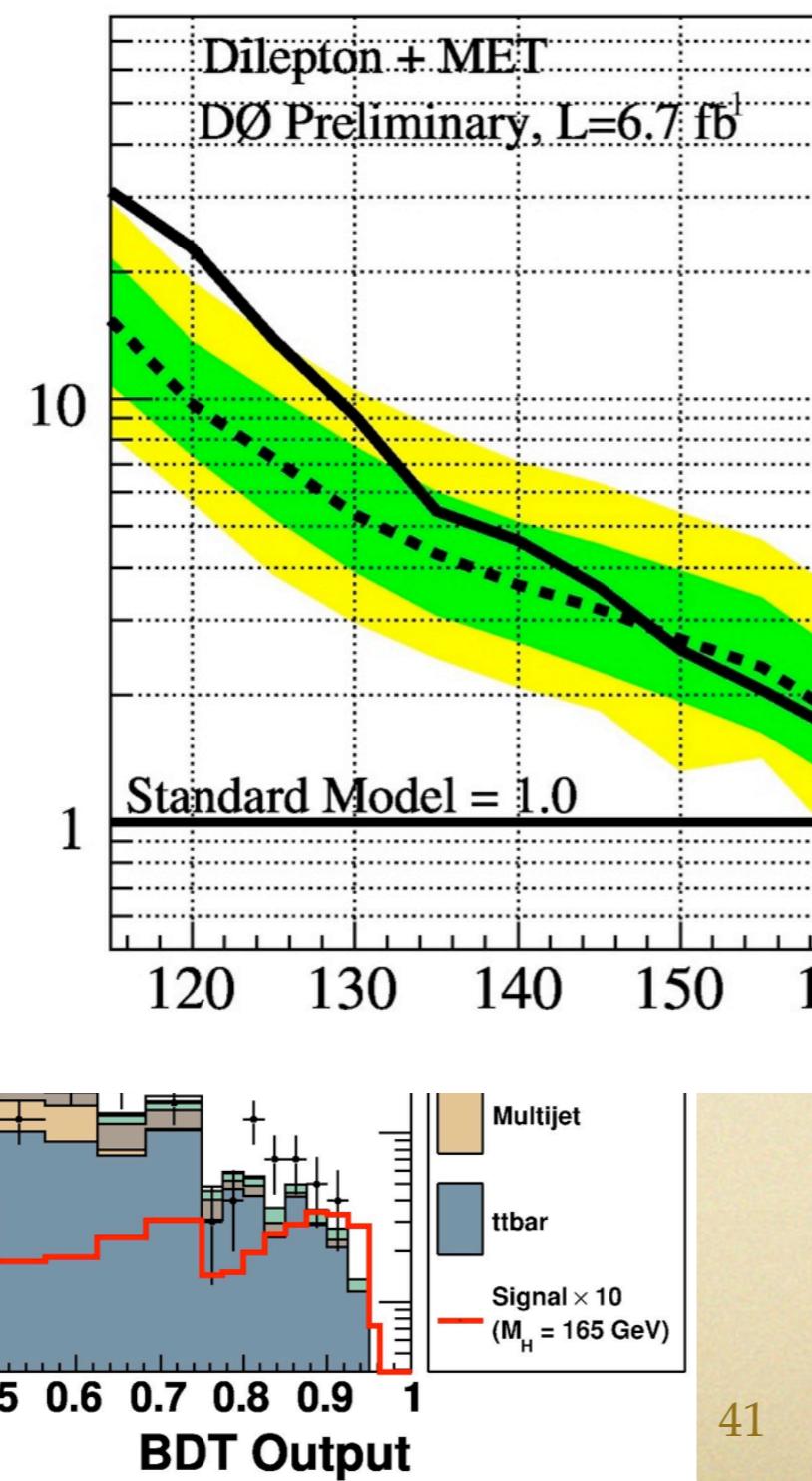


# $\bar{p}p \rightarrow H \rightarrow WW^* \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ Channel

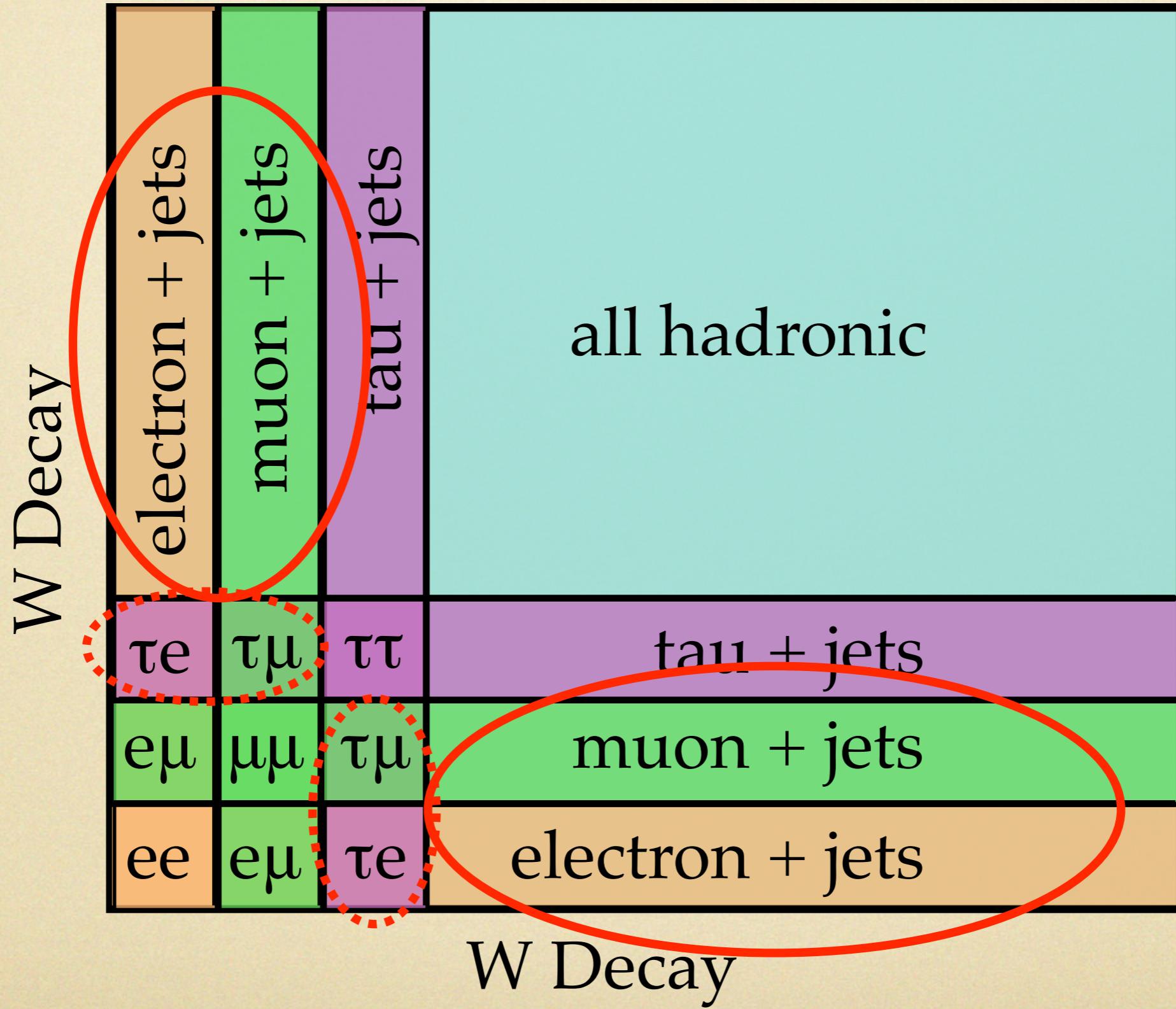


- Extended  $e\mu$  analysis
  - \* Separate by N-jets

\*  $\text{U}_M$   
 \*  $\text{U}_L$   
 \*  $\text{Co}_L$



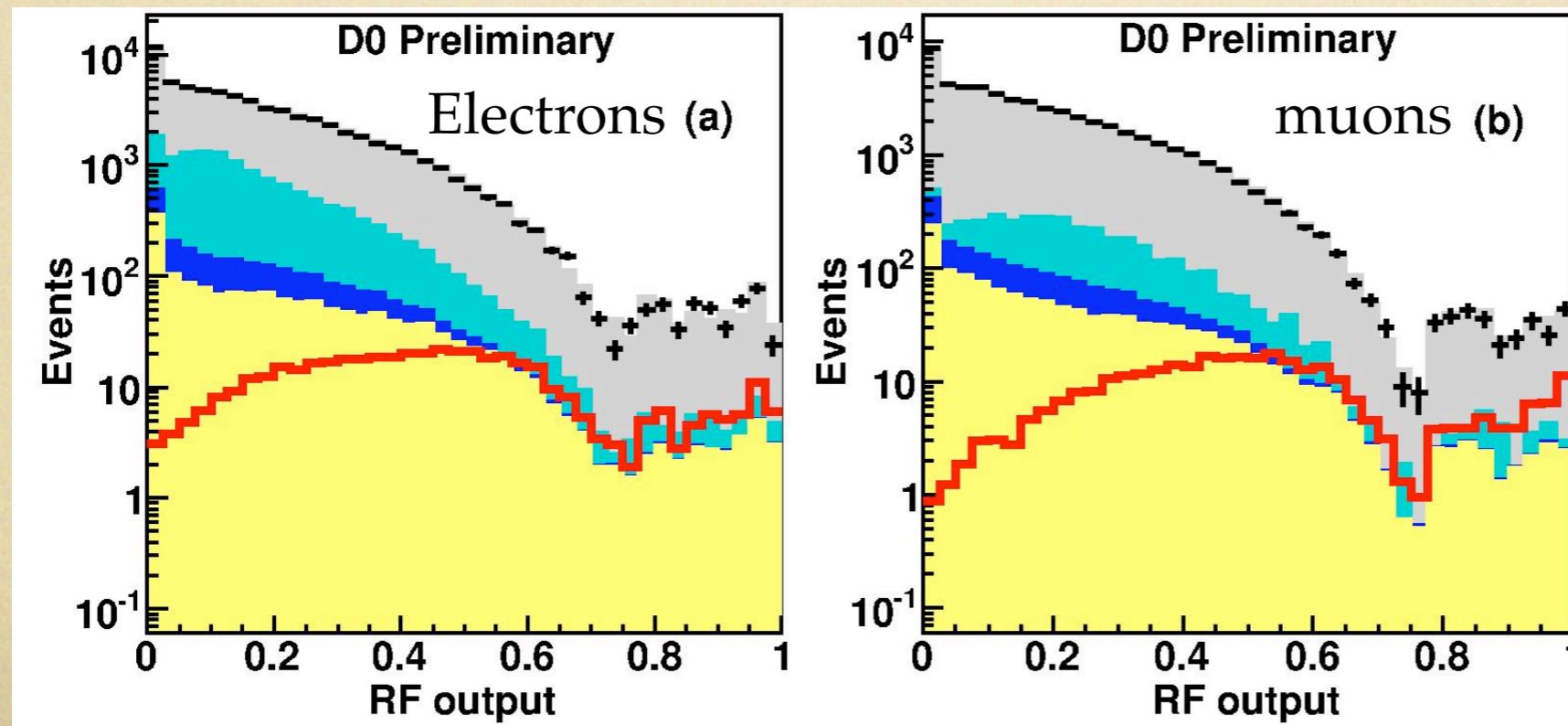
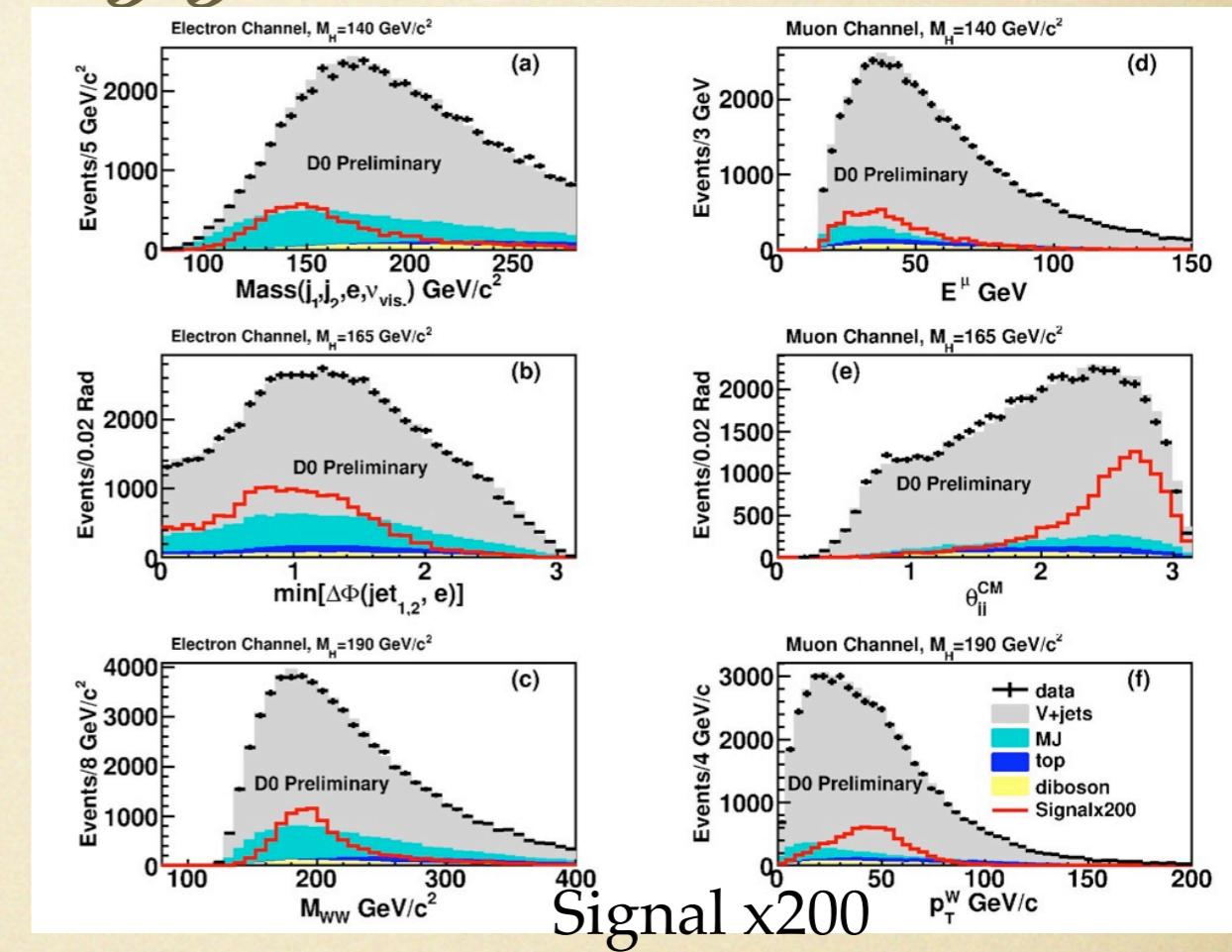
# High Mass WW Final States



# $H \rightarrow WW \rightarrow \ell\nu jj$ Channel



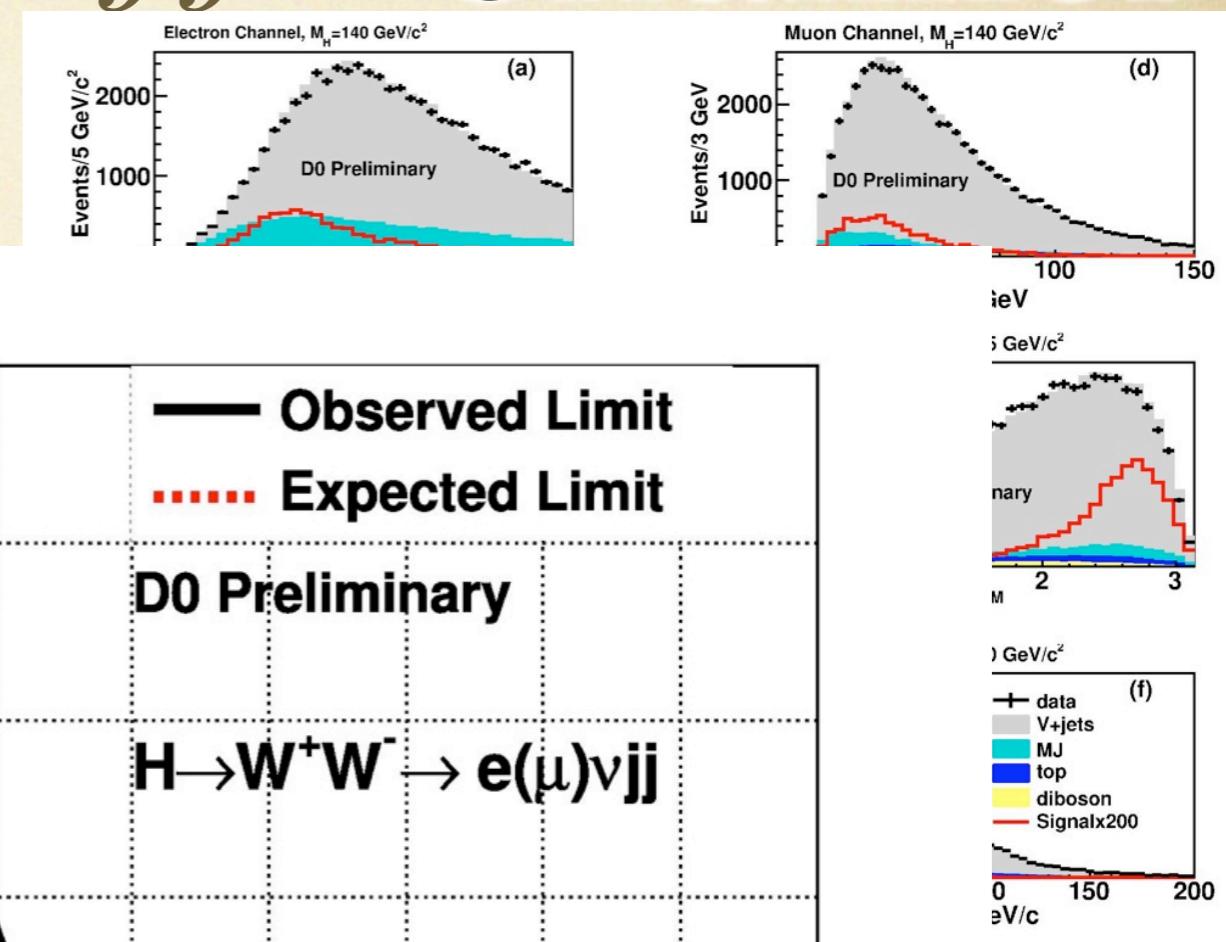
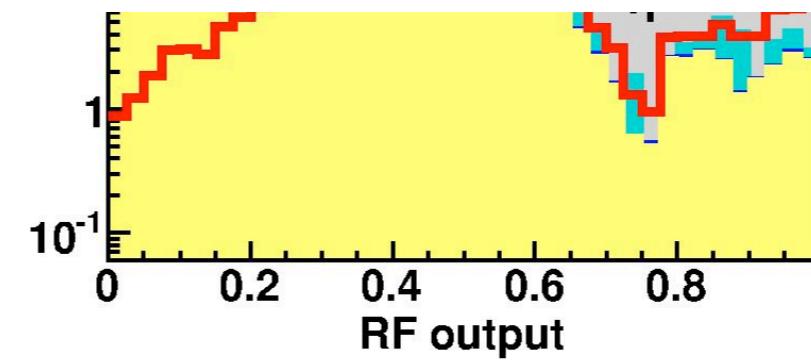
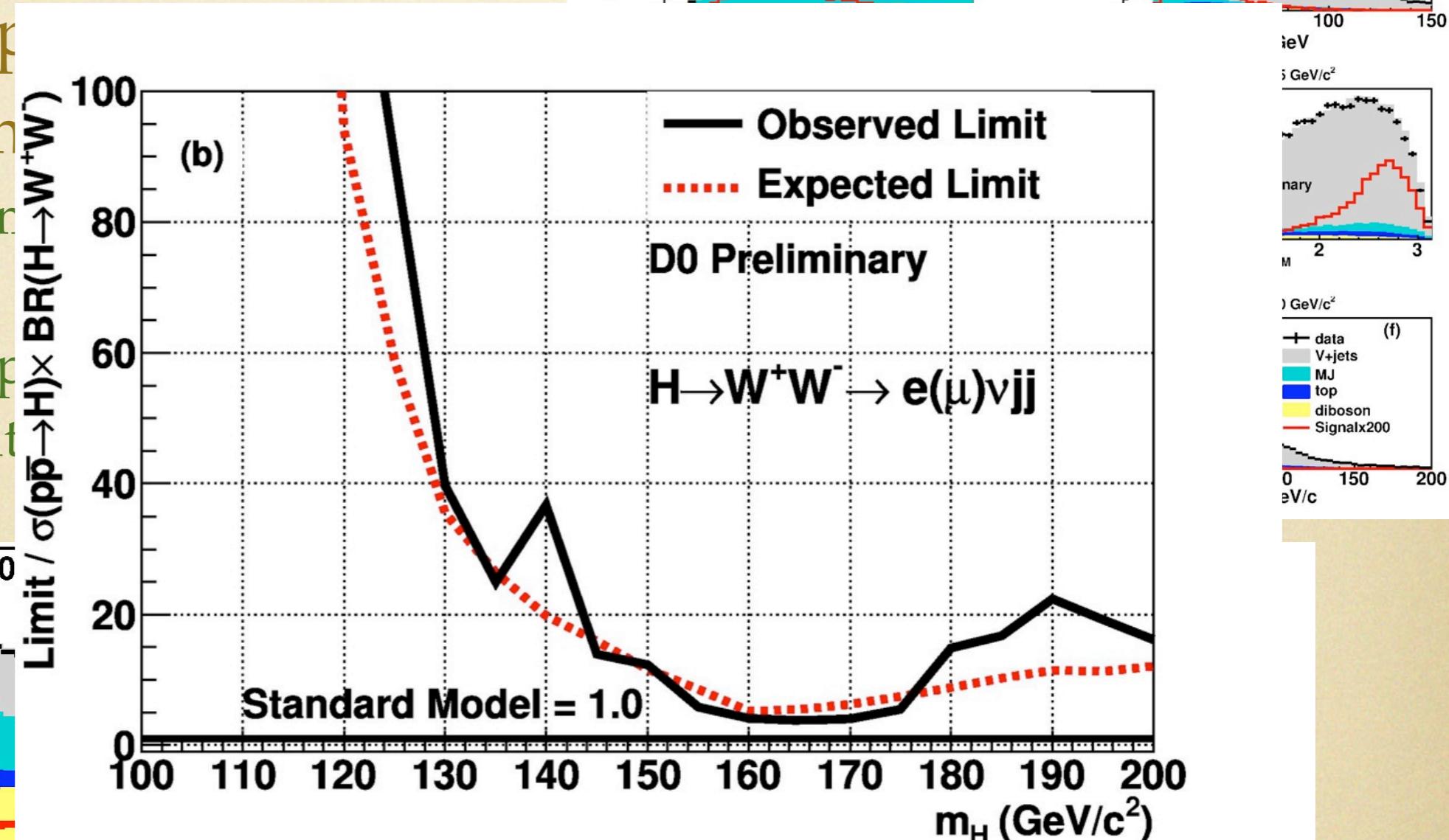
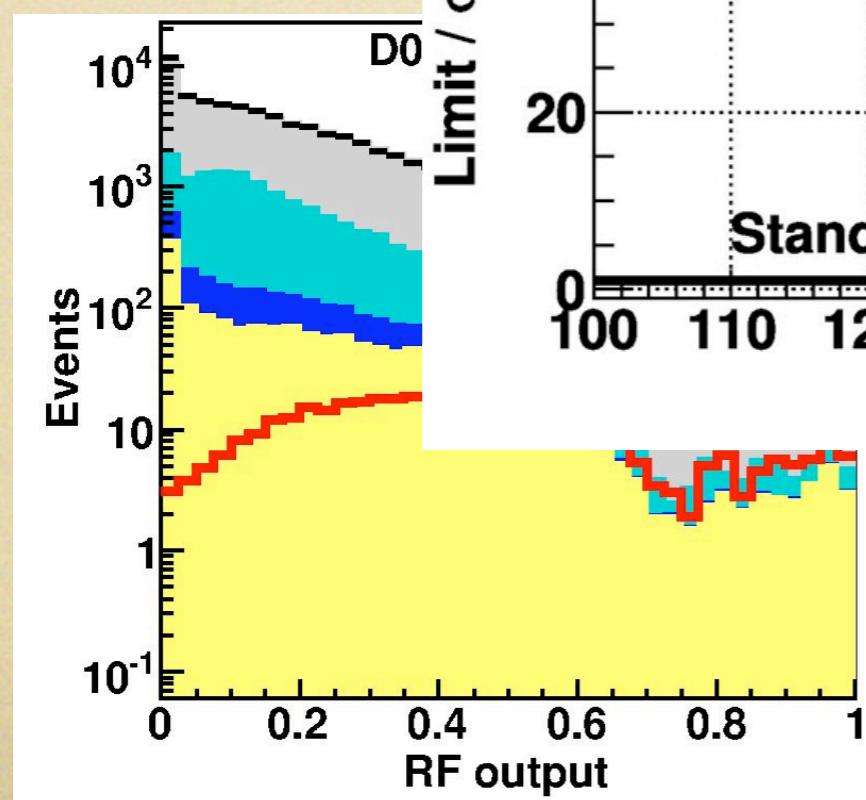
- High  $P_T$  e or  $\mu$  and  $E_T$
- V+jets primary bkg
- Discriminant
  - \* Random Forest of Decision Trees.
  - \* ~30 Topological/Kinematic Quantities



# $H \rightarrow WW \rightarrow \ell\nu jj$ Channel



- High  $P_T$  e or  $\mu$  and  $E_T$
- $V+jets$
- Discrim.
- \* Random Trees.
- \* ~30 Top Quantit



Signal x10

$$H \rightarrow WW \rightarrow \ell\nu\tau\nu$$

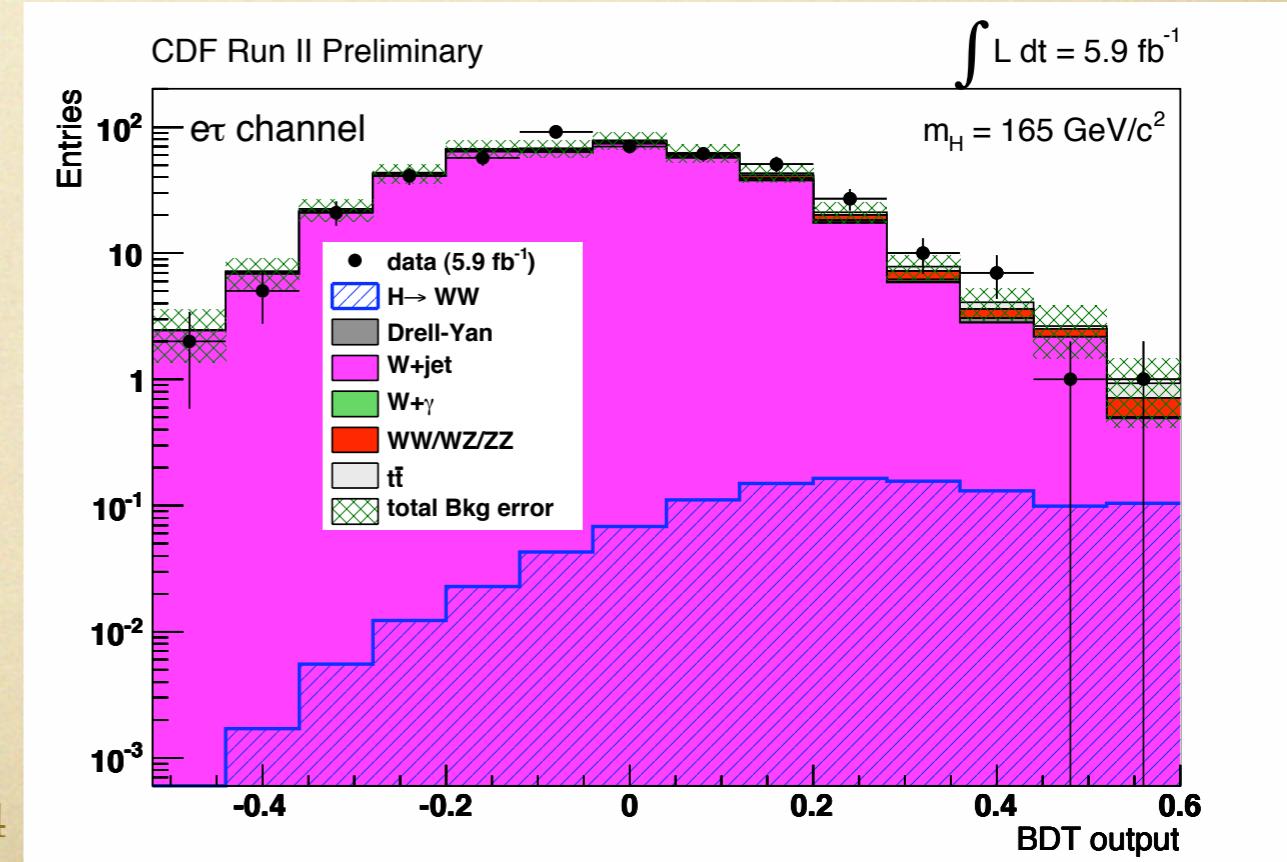
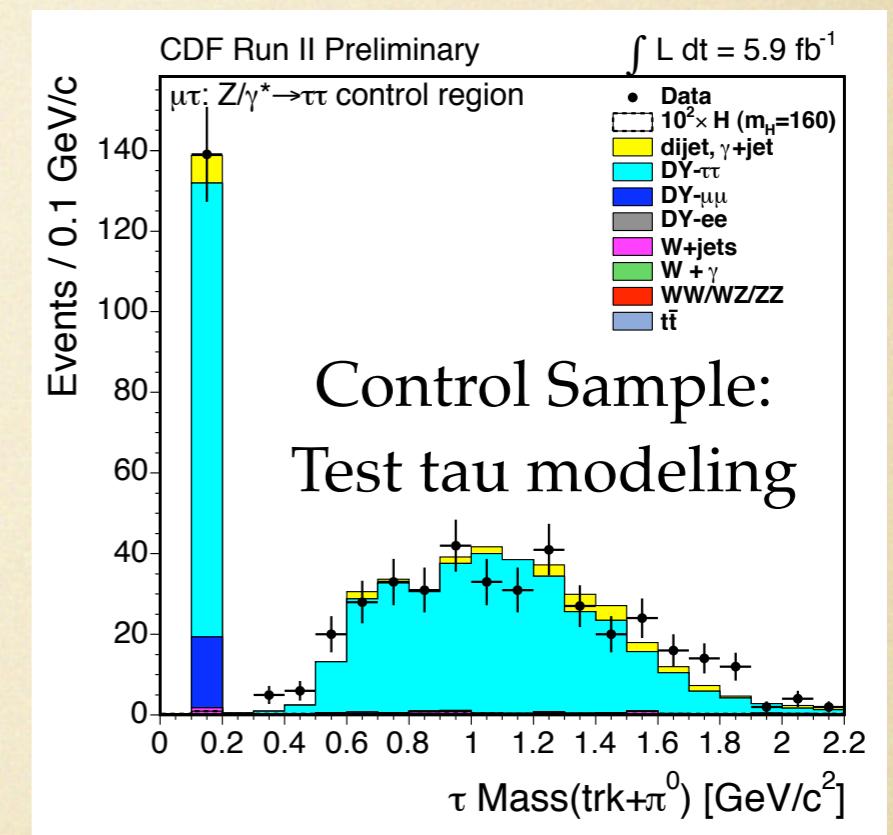


- High  $P_T$  e or  $\mu$  and  $E_T$
- hadronic tau (1 or 3 prong)
- Discriminant
  - \* Boosted Decision Trees.
  - \* Tau ID quantities input
  - \* Topological/Kinematic Quantities

Data: 741 Events

Sample	Events
Background	$726 \pm 82$
gg $\rightarrow H$	$1.08 \pm 0.1$
WH	$0.26 \pm 0.03$
ZH	$0.17 \pm 0.02$
VBF	$0.10 \pm 0.01$

# Channel



$$H \rightarrow WW \rightarrow \ell\nu\tau\nu$$

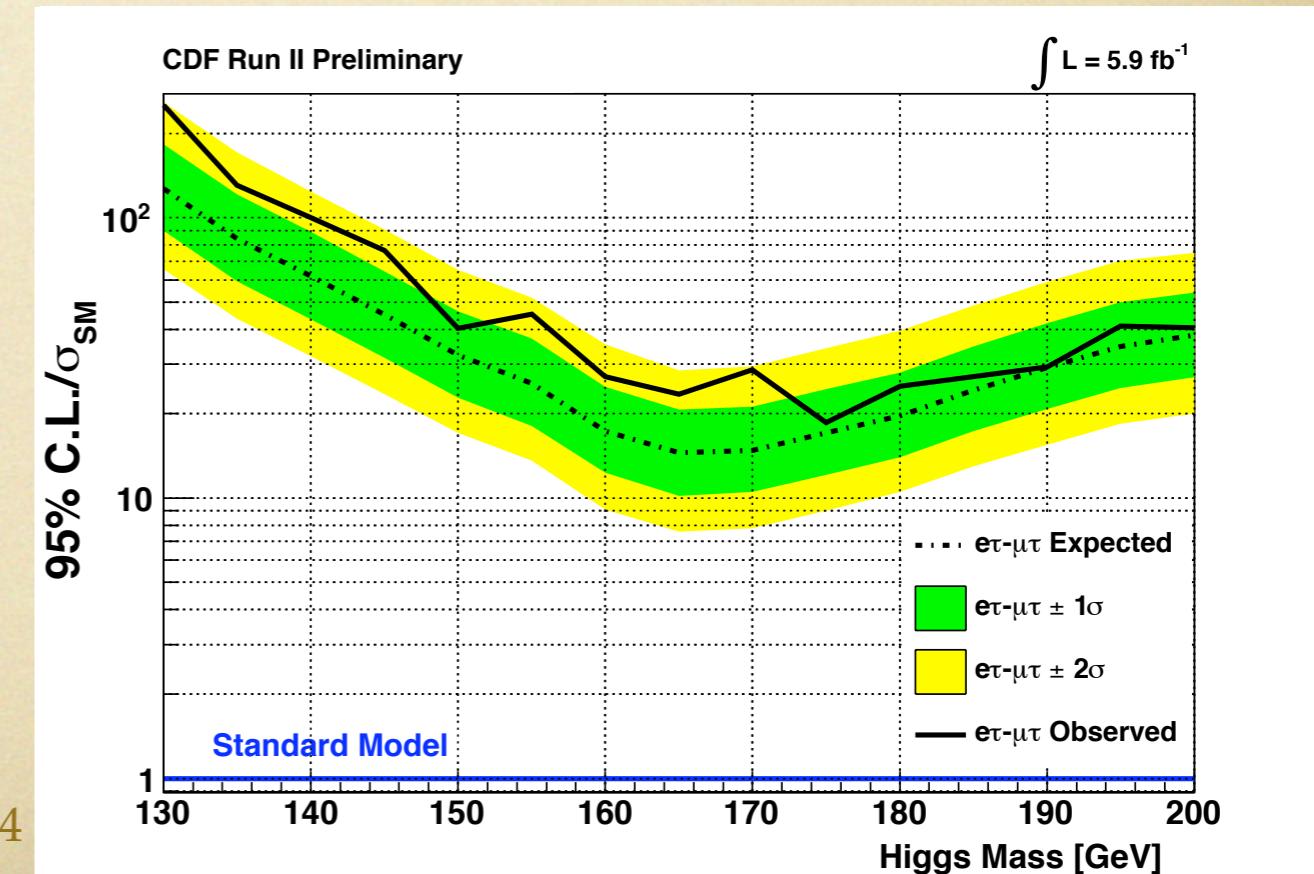
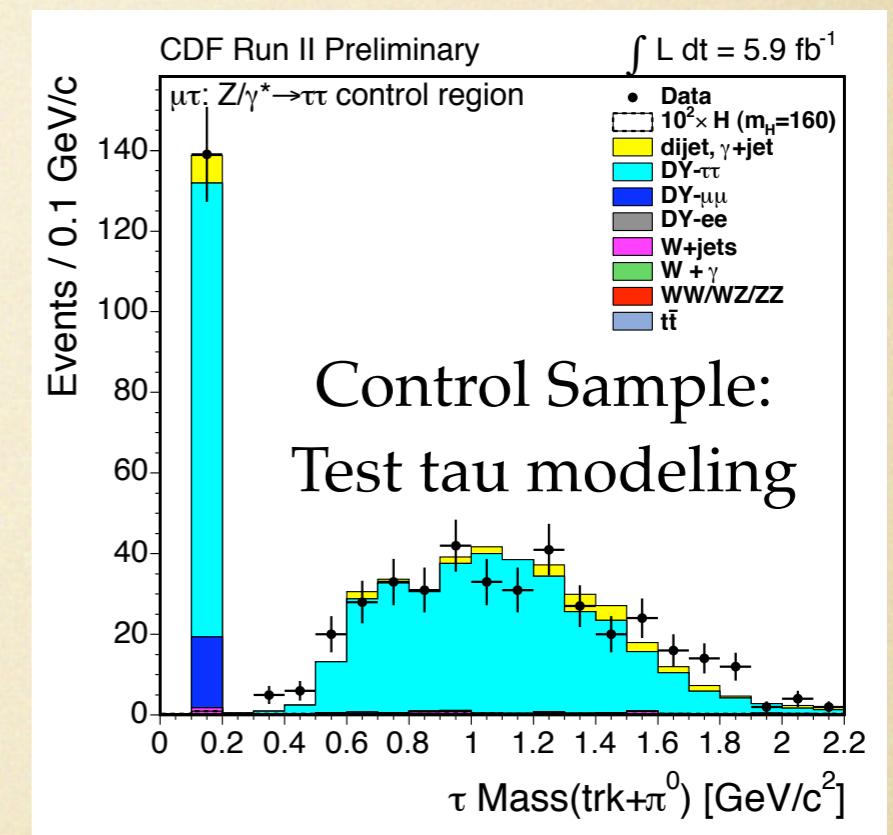


- High  $P_T$  e or  $\mu$  and  $E_T$
- hadronic tau (1 or 3 prong)
- Discriminant
  - \* Boosted Decision Trees.
  - \* Tau ID quantities input
  - \* Topological/Kinematic Quantities

Data: 741 Events

Sample	Events
Background	$726 \pm 82$
gg $\rightarrow H$	$1.08 \pm 0.1$
WH	$0.26 \pm 0.03$
ZH	$0.17 \pm 0.02$
VBF	$0.10 \pm 0.01$

# Channel



# Other Channels



...leave no stone unturned!

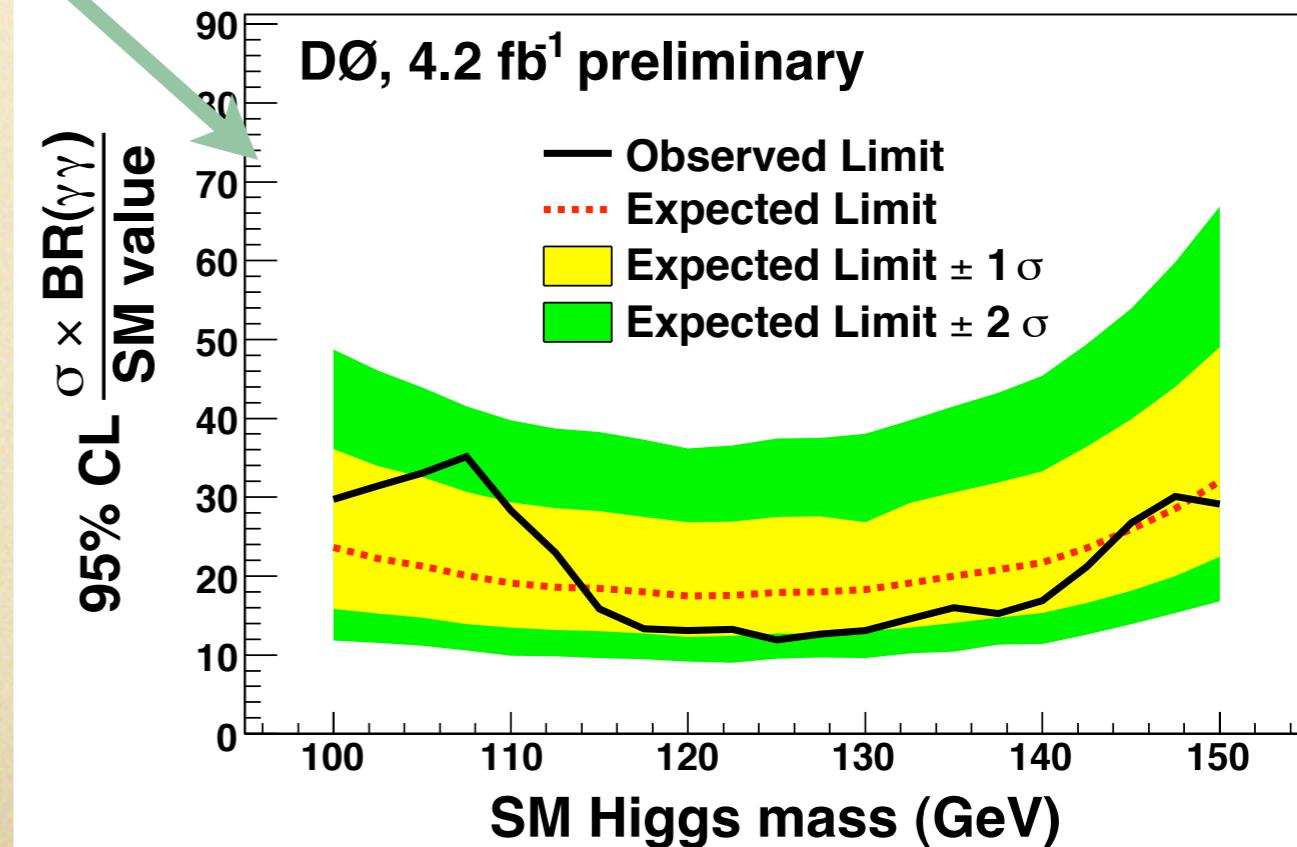
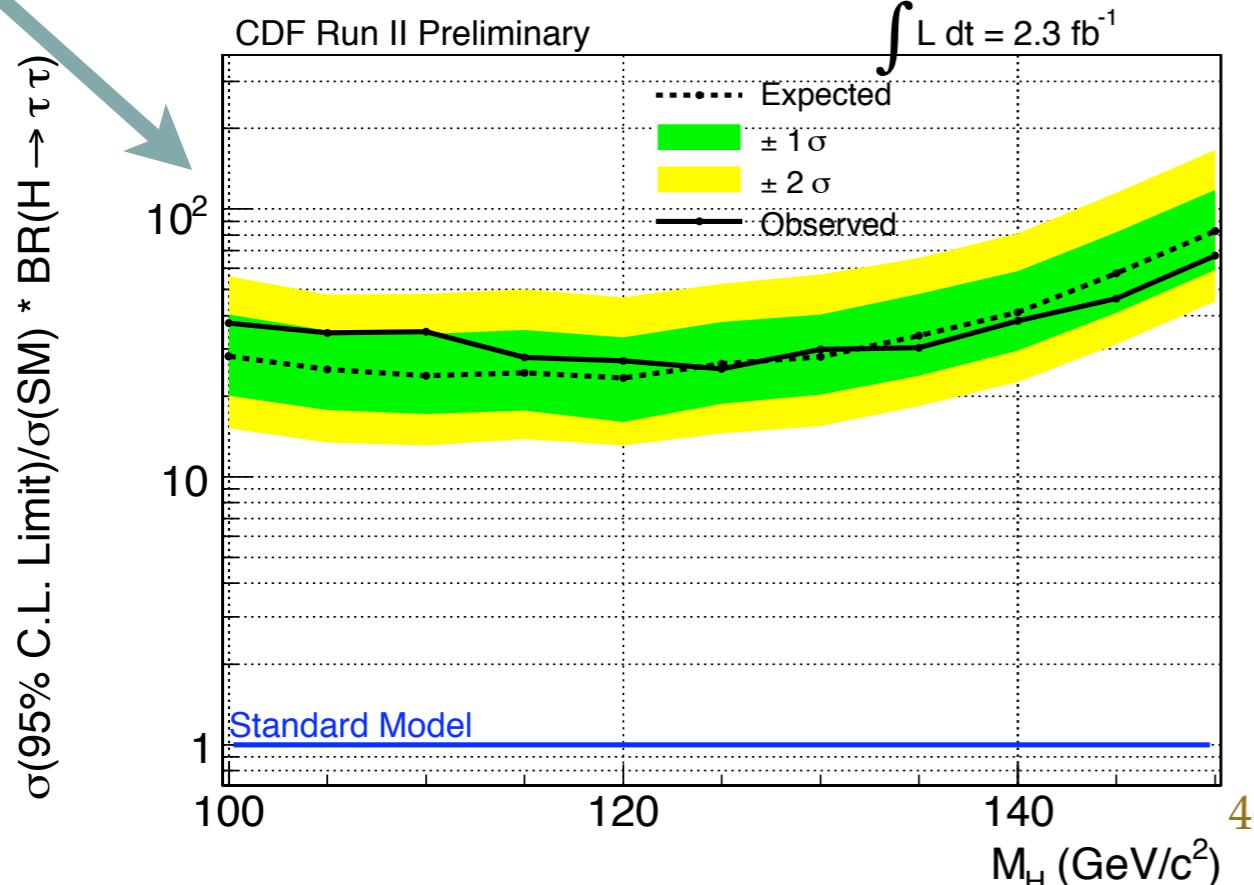
# Other Channels...

- Other decay chains are also being considered
- IF the SM is correct, these are not as sensitive
- BUT, every little bit helps and nature could be different.

$t\bar{t}H \rightarrow \ell\nu qq'bbbb$   
 $WH \rightarrow WWW^*$   
 $VH, VBF, H \rightarrow \tau\tau + 2j$



$H \rightarrow \tau\tau$   
 $WH \rightarrow WWW^*$   
 $\bar{p}p \rightarrow H \rightarrow \gamma\gamma$



# 4<sup>th</sup> Step...Channel Combination

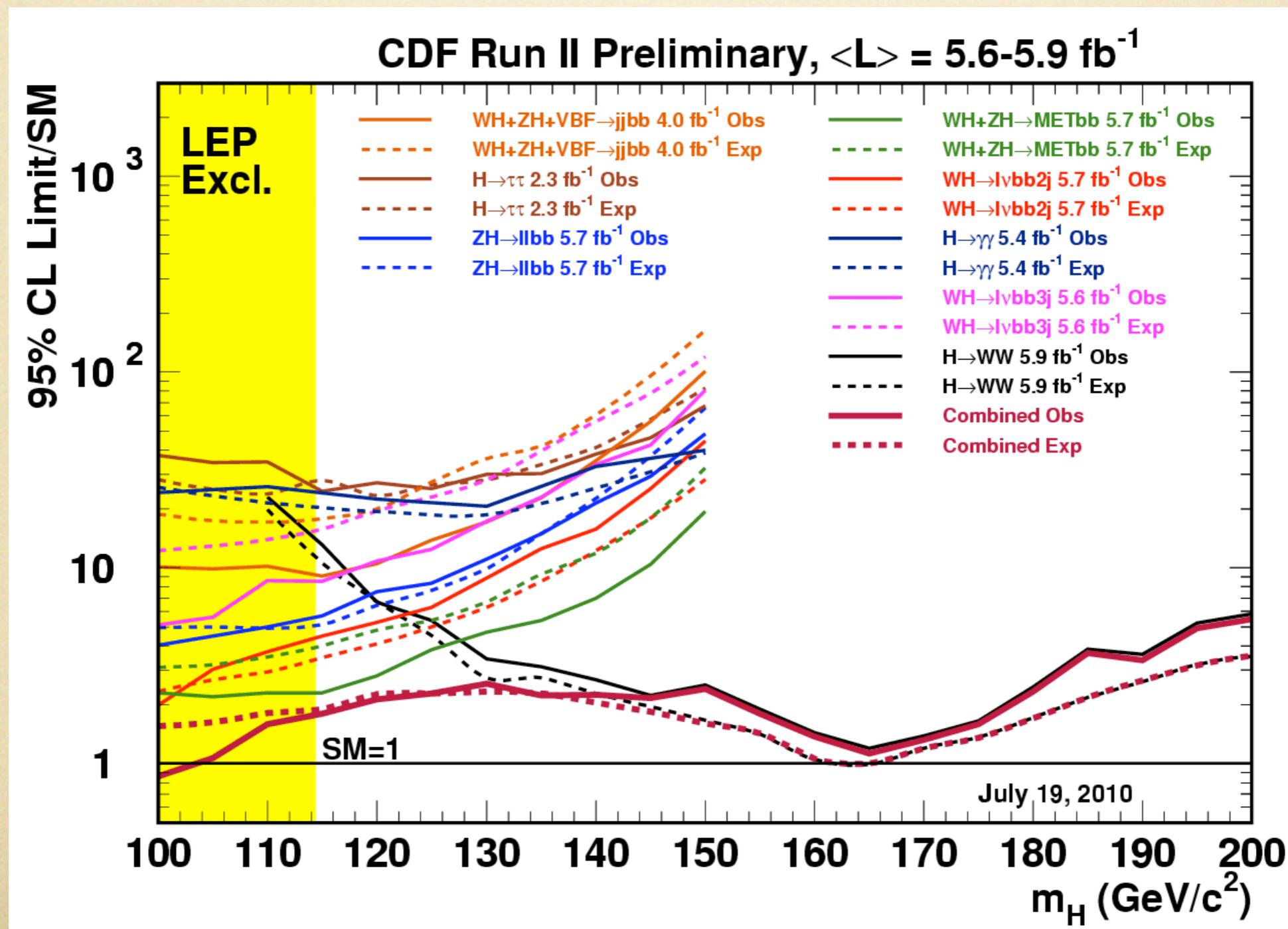
No Single Decay Channel Has Sufficient Power to reach the SM prediction.

# 4<sup>th</sup> Step...Channel Combination

No SM  
Pc

- Statistically Combine Channels.
- Use a procedure to properly account for correlated uncertainties.

fficient  
ion.

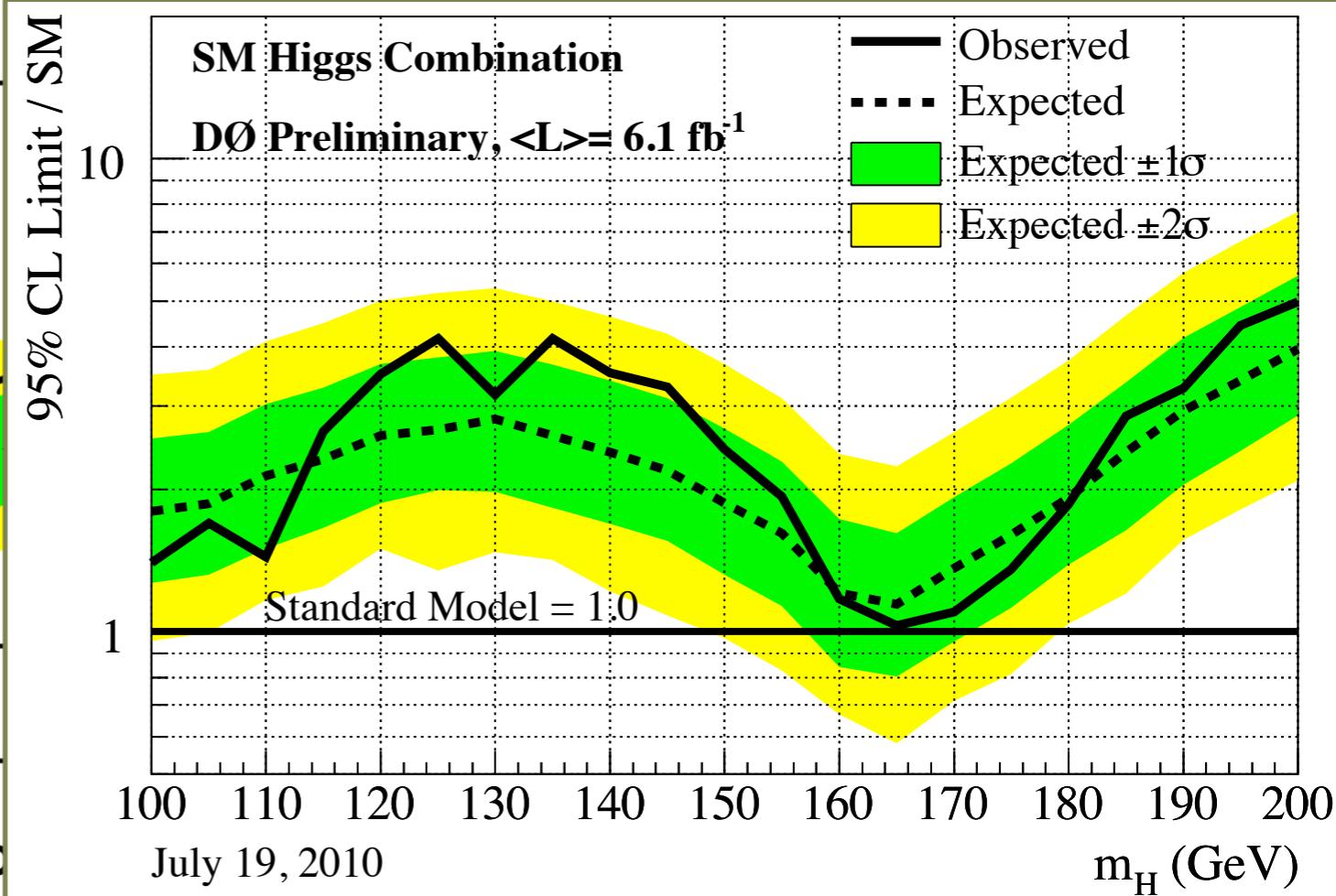
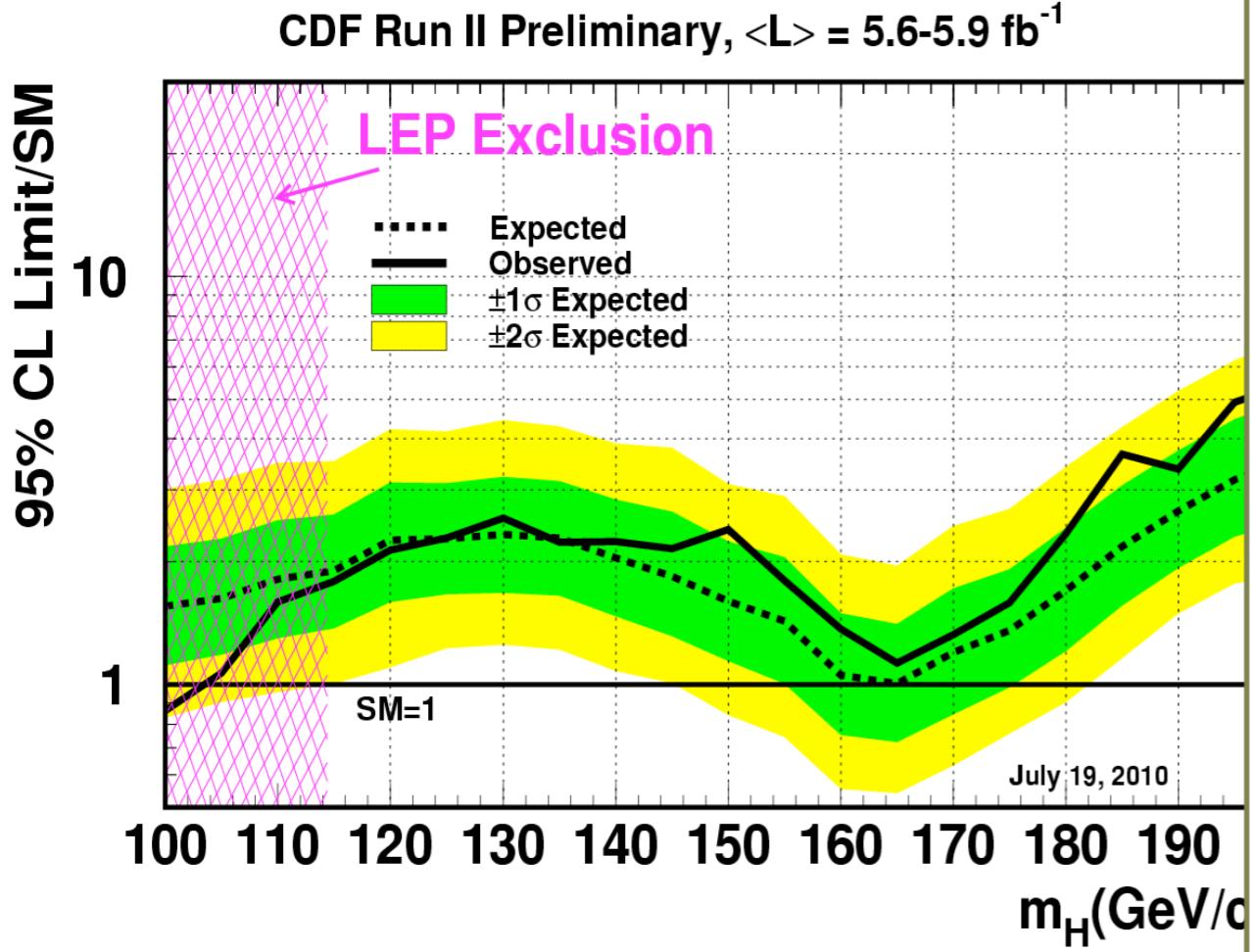


# 4<sup>th</sup> Step...Channel Combination

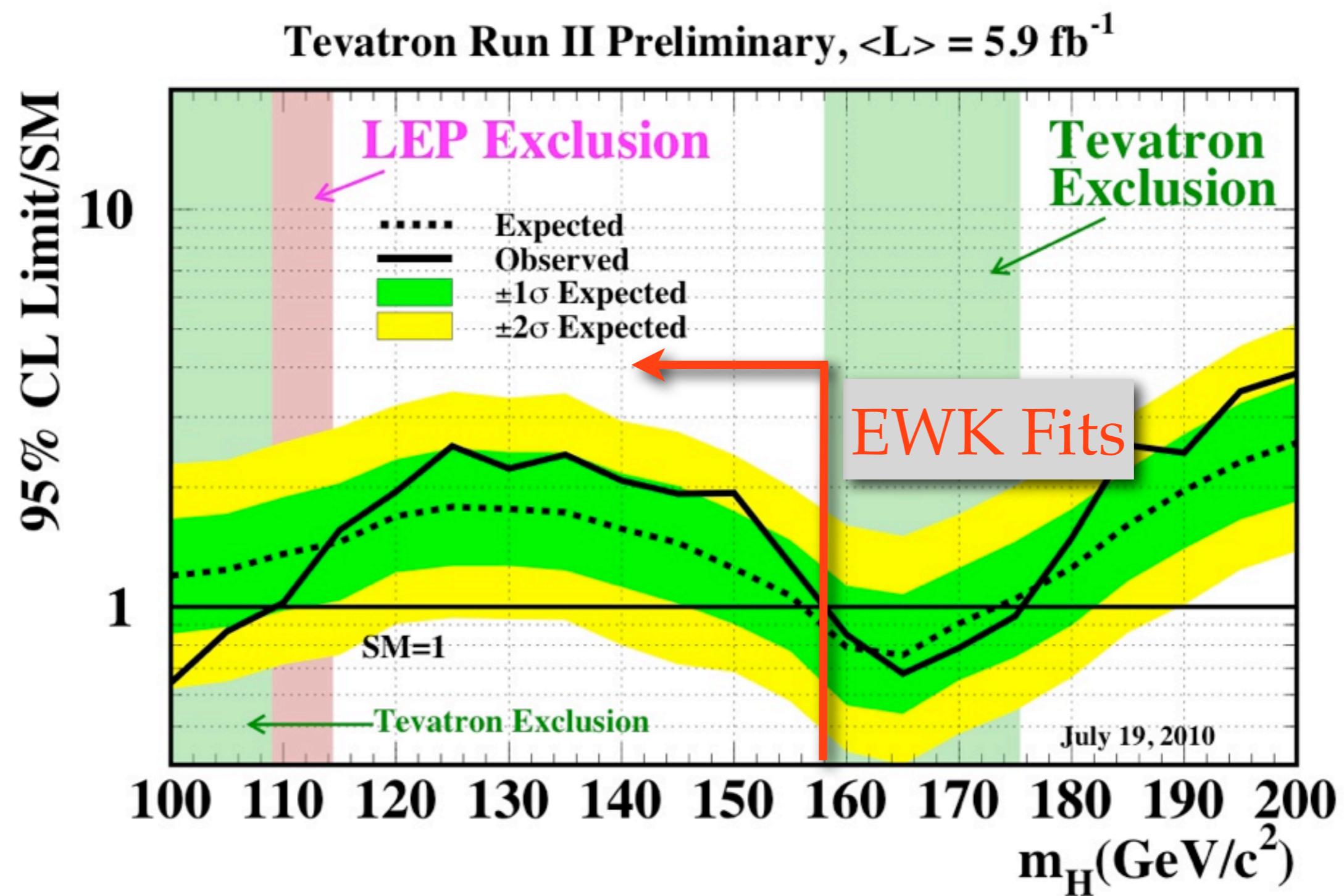
No S  
Pc

- Statistically Combine Channels.
- Use a procedure to properly account for correlated uncertainties.

fficient  
ion.

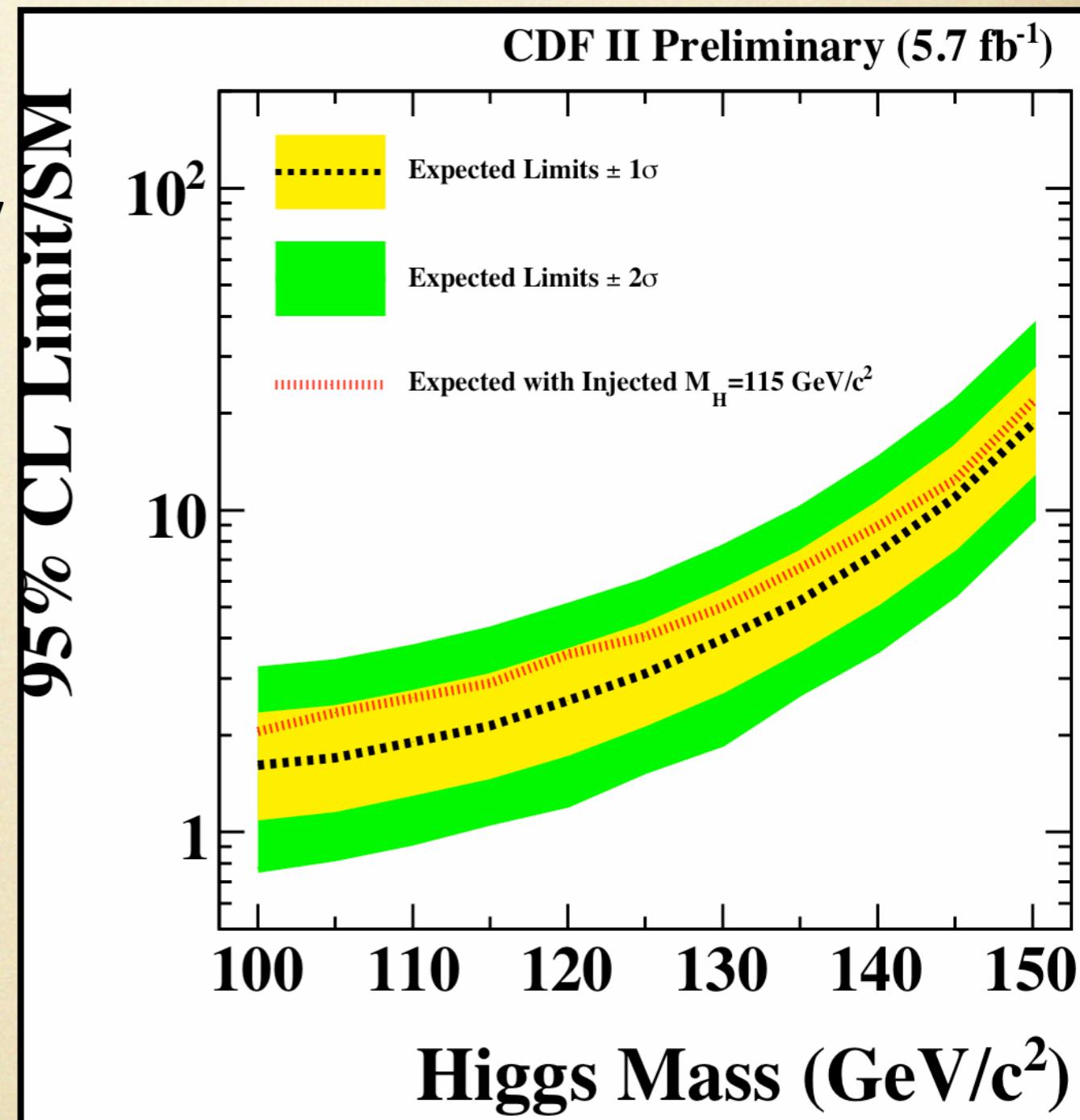


# 5<sup>th</sup> Step...Tevatron Combination



# If Higgs is there...

- $\text{lvbb}$ ,  $\text{METbb}$ , and  $\text{llbb}$  channels included
- Inject  $\text{SM}^*1.0$  signal at  $m_H=115 \text{ GeV}$  on top of  $\text{SM}$  backgrounds, and generate pseudoexperiments with that.
- Analyze 115 signal+background pseudoexperiments at other test masses –100 GeV to 150 GeV
- Find the median expected limit with injected signal and compare with the distribution of limits when the signal is completely absent.



# Future Prospects



Department of Energy  
Office of Science  
Washington, DC 20585

JAN 6 2011

Office of the Director

Professor Melvyn Shochet  
Chairman, High Energy Physics Advisory Panel  
Department of Physics  
University of Chicago  
5630 S. Ellis Ave  
Chicago, IL 60637

Dear Professor Shochet:

I am writing to convey the Office of Science's response to the recent High Energy Physics Advisory Panel (HEPAP) report on extending the operation of the Tevatron at Fermi National Accelerator Laboratory. As you know the Office of Science received in the summer of 2010 a widely supported proposal to extend operation of the Tevatron through FY 2014. At our request, LEDAD and its subpanel, Particle Physics Division,

Unfortunately, the current budgetary climate is very challenging....operation of the Tevatron will end in FY2011...

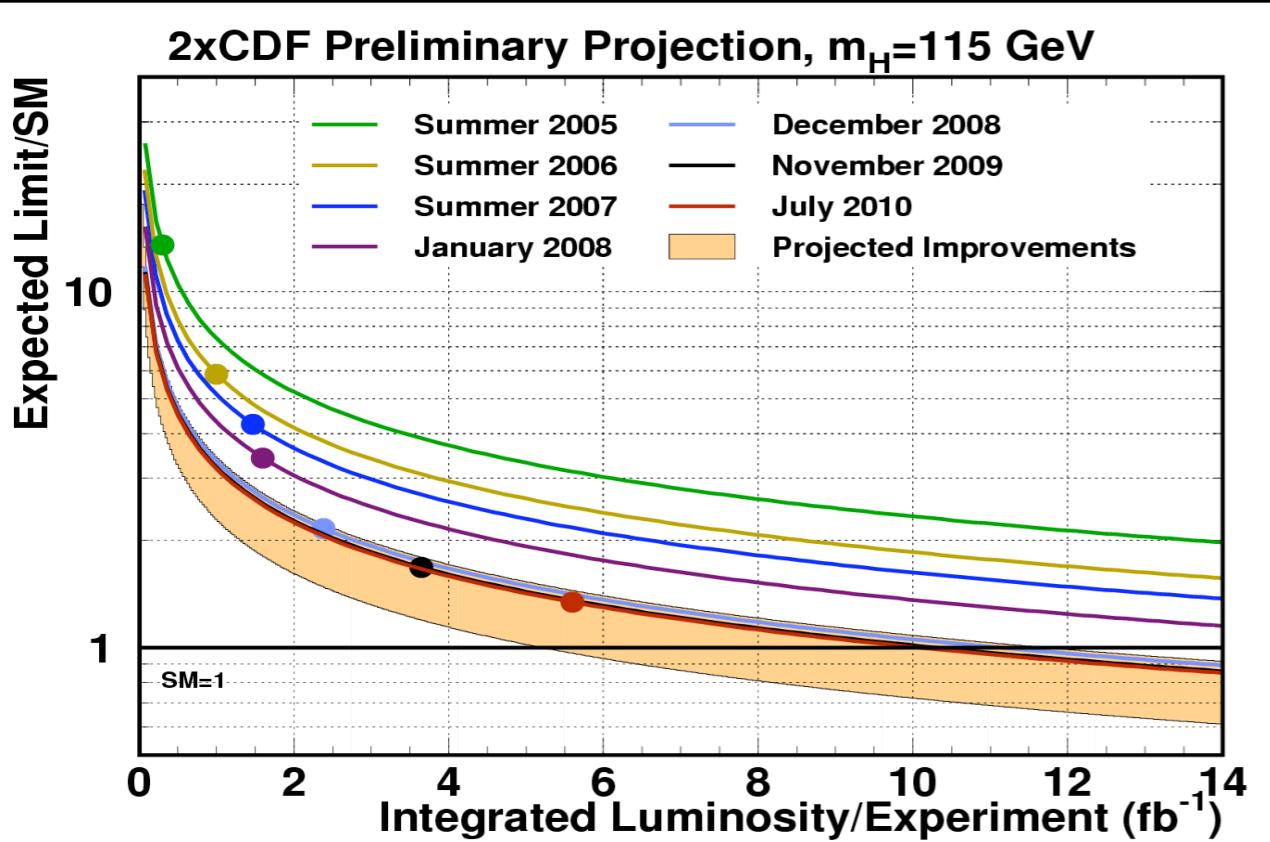
Based on the challenging financial climate, the Office of Science, based in part on the P5 recommendation, operation of the Tevatron will end in FY 2011, as originally scheduled.

The strategic plan for the U.S. particle physics program, developed by P5, attacks the most important scientific questions in three broad areas of the field: the Energy, Intensity,

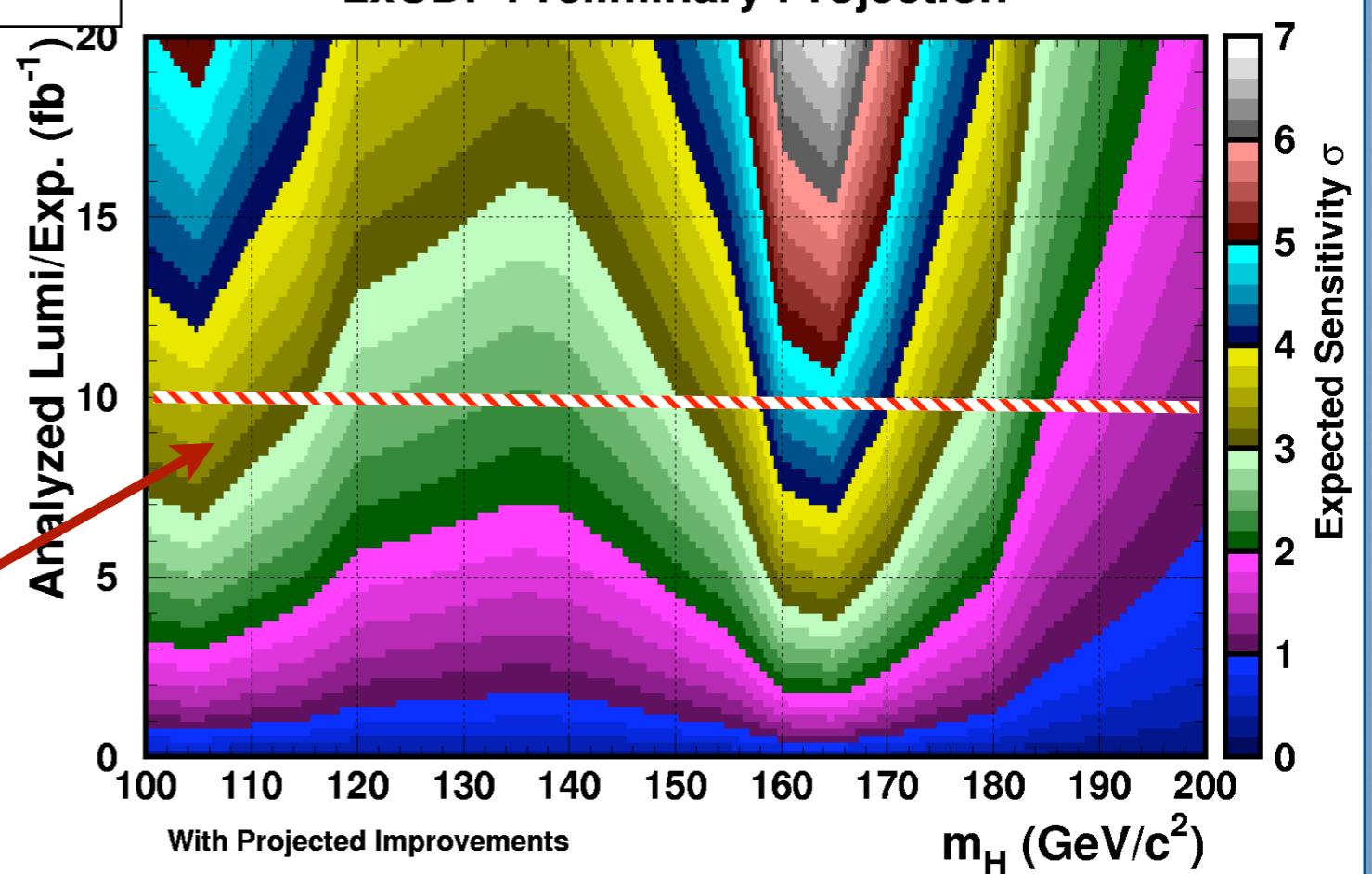
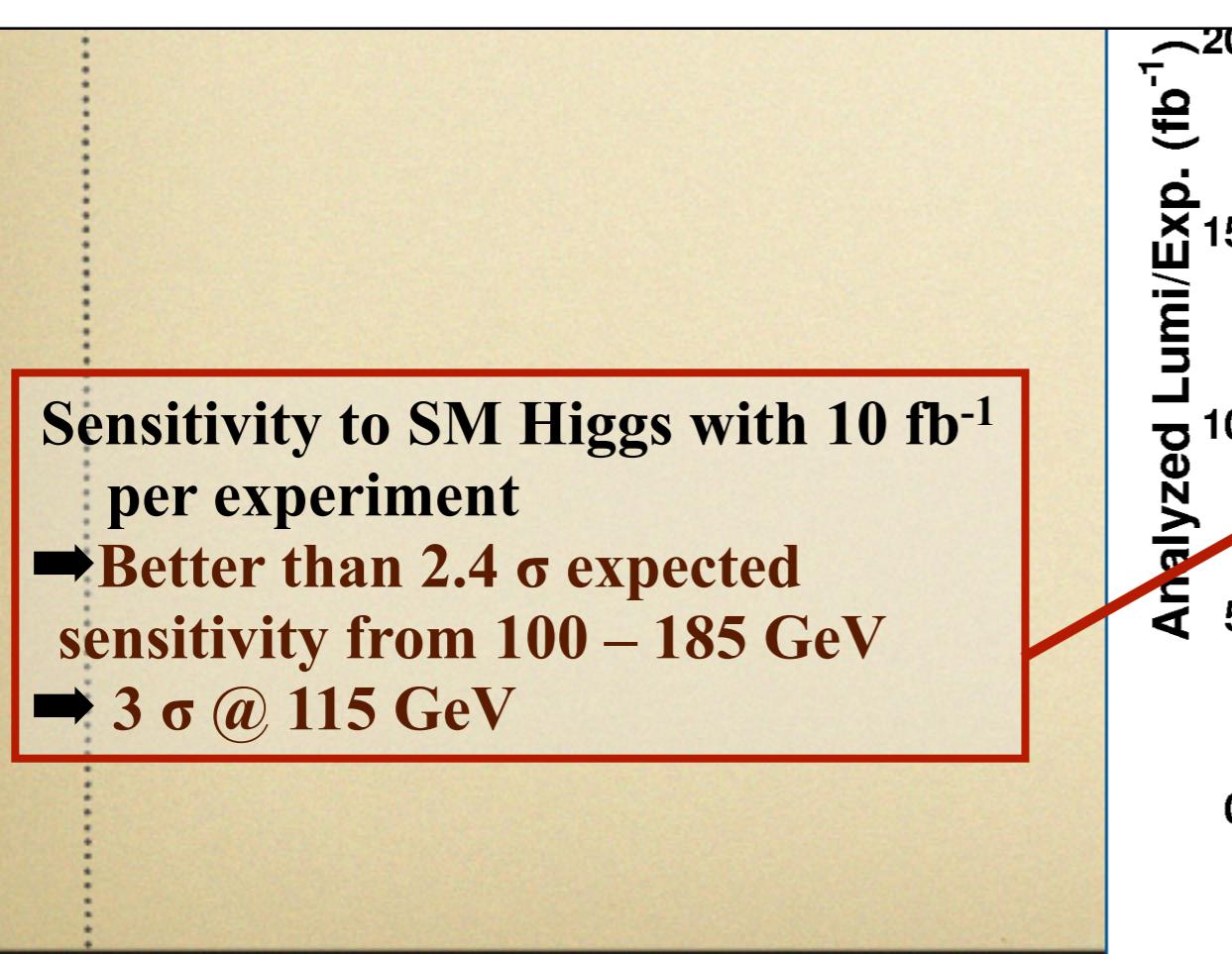


Printed with soy ink on recycled paper

# Future Prospects



Recorded luminosity now  
 $\sim 9 \text{ fb}^{-1}$  per experiment  
 Final analyzable data set  
 $\sim 10\text{-}11 \text{ fb}^{-1}$  per experiment



# Summary

- Higgs search at Fermilab is very mature.
- The collaborations are squeezing every last bit of sensitivity from all channels.
- Improvements continue to occur and are being extended from one channel to another.
- The Tevatron has begun squeeze where the Higgs can exist.
- With  $10\text{-}11 \text{ fb}^{-1}$ , excellent chance for pushing lower limit  $>115 \text{ GeV}/c^2$  (assuming Higgs is not there).
- Unfortunately the Tevatron is scheduled to turn off at the end of FY2011 (Sept 30th).
- But the ideas and techniques developed will certainly carry over to the LHC.

# More information:



<http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm>



<http://www-cdf.fnal.gov/physics/new/hdg/Results.html>



<http://tevnphwg.fnal.gov/>

# Backup Slides



# Treatment of Theoretical Uncertainties

---

- Arguments for using larger than normal scale variations ( $k=3$  or  $m_H/3 < \mu_r, \mu_f < 3m_H$ ) as opposed to standard factor of two ( $k=2$ ) because of large NLO and NNLO contributions
  - Not the consensus of the theoretical community. In particular, authors of the papers from which our gluon fusion cross sections and uncertainties are taken disagree
- Arguments for additional uncertainties from Effective Field Theory (EFT) approach for integrating EWK contributions from heavy and light loop particles
  - Our quoted uncertainties do include a 1-2% contribution for this effect. If the corrections introduced by the EFT approach are removed entirely (clearly conservative), the total cross section is found to change by less than 4%
- Arguments that our PDF uncertainties should account for observed differences in cross sections obtained using our default MSTW model and the ABKM/HERAPDF models



# Treatment of Theoretical Uncertainties

---

- ABKM and HERPDF fits do not include Tevatron jet data, which provide the best constraints on the relevant high-x gluon distributions at Tevatron energies. NLO theoretical predictions using ABKM/HERAPDF are in poor agreement with Tevatron jet data
- Arguments for accounting for correlations between scale and PDF model uncertainties
  - Our quoted scale uncertainties do include contributions from PDF model scale dependence. These contributions are found to be small in comparison with experimental uncertainties on the datasets used in the PDF model fits
- Arguments that theoretical cross section uncertainties should be added linearly even if they are not correlated
  - Our 95% C.L. exclusion range for  $m_H$  is necessarily a probabilistic statement. To be consistent and accurate all experimental and theoretical uncertainties must be treated equivalently (accounting for the proper correlations)



# Reproduction of Tevatron Limits

---

- Independent re-interpretations of Tevatron Higgs mass exclusion ranges should be received with skepticism
- The examples we have seen are based on incorrect assumptions regarding the experimental methodology
- Some examples of inaccurate assumptions
  - That the effect of an increase in uncertainty on a theoretical cross section can be modeled using an equivalent decrease in the central cross section value
  - That increases in cross section uncertainties assigned to background processes effect our final limits. In fact, main background contributions are constrained directly from our fit to the data more accurately than what one obtains using even our current theoretical uncertainties
  - That it is not important to account for correlations between different search channels. In fact, these correlations allow us to obtain additional constraints using the fitting procedure applied to the data